AQUACULTURE WASTEWATER TREATMENT:

WASTEWATER CHARACTERIZATION AND DEVELOPMENT OF APPROPRIATE TREATMENT TECHNOLOGIES FOR THE NEW BRUNSWICK SMOLT PRODUCTION INDUSTRY

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FINAL REPORT

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EXECUTIVE SUMMARY

The environmental impact of intensive fish culture has long been discussed, however, implementation of economically feasible and effective technologies for effluent treatment remains minimal on an industry-wide scale. The design of treatment units requires a fundamental understanding of all aspects of fish culture and wastewater engineering. This extensive field study examines commercial fish production practices, culture facilities design, suspended solids settling behaviour, and critical design parameters of existing effluent treatment operations, in an effort to identify those factors which most significantly affect effluent quality and management. An emphasis has been placed upon commercial culture of Atlantic Salmon smolts in the province of New Brunswick; however, for comparative purposes, data have been included from a similar study conducted at intensive Rainbow Trout culture operations in Ontario.

The design of culture units and specific culture/management practices are the principal factors governing effluent water quality. Most interestingly, for a given volumetric flow of water, no difference was observed in the carrying capacity (kg fish/Lps) of different facility designs; however, effluent water quality was found to vary quite substantially, suggesting that certain designs are much more polluting. Sedimentation practices (i.e. gravity settling) tend to be most widely applicable in intensive salmonid aquaculture; they require no energy input or specialized operating skills, are relatively inexpensive to install and operate, and can be easily incorporated into both new and existing facilities. A detailed overview of sedimentation design for intensive smolt culture operations is included.

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Laboratory facilities were provided by Mr. Don Hicks and the Fredericton Laboratory of the Department of the Environment. All water quality analyses for nutrient sampling were conducted by Laboratory staff.

The comments and constructive criticism offered by the members of the project review committee have enhanced the quality and presentation of the final report. Mr. Keith Somers (Ontario Ministry of the Environment, Water Resources Branch, Toronto) provided invaluable assistance with statistical analyses. Many thanks are extended to the private and government aquaculturists throughout New Brunswick who permitted us to visit their operations to obtain the water quality samples and information which we required.

TABLE OF CONTENTS

EXECUTIVE SUMMARY i

ACKNOWLEDGEMENTS i

TABLE OF CONTENTS ii

1.0 INTRODUCTION 1
- 1.1 Aquaculture in New Brunswick 1
- 1.2 Environmental Impact of Intensive Salmonid Aquaculture 1
  - 1.2.1 Suspended Solids Production in Intensive Salmonid Culture 3
  - 1.2.2 Phosphorus Production in Intensive Salmonid Culture . . 3
- 1.3 Project Purpose and Objectives 5

2.0 TECHNOLOGIES FOR AQUACULTURE EFFLUENT TREATMENT 8

3.0 SEDIMENTATION TECHNOLOGIES FOR AQUACULTURE WASTEWATER TREATMENT . . 9
- 3.1 Fundamental Concepts of Sedimentation 9
- 3.2 Factors Influencing the Design of Sedimentation Basins 13
  - 3.2.1 Tank Velocity, Turbulence & Scour 13
  - 3.2.2 Short-Circuiting & Tank Stability 15
  - 3.2.3 Inlet & Outlet Design Considerations 16
  - 3.2.4 Principal Design Considerations 19

4.0 CHARACTERIZATION OF AQUACULTURE OPERATIONS & EFFLUENTS 24
- 4.1 Purpose & Objectives 24
- 4.2 Field Survey & Water Quality Sampling 25
  - 4.2.1 Predictor Variables 26
  - 4.2.2 Response Variables 27
  - 4.2.3 Scope and Limitations 28
- 4.3 Data Analysis & Results 29
- 4.4 Chapter Summary and Principal Findings 37

5.0 STATUS OF AQUACULTURE EFFLUENT TREATMENT 47
- 5.1 Current Application of Settling Facilities in Aquaculture . . . 47
- 5.2 Effectiveness of Existing Treatment Operations 48
- 5.3 Chapter Summary - Principal Findings 50

6.0 IMPLEMENTATION OF AQUACULTURE EFFLUENT TREATMENT 54
- 6.1 Commercial Fish Production Facilities in New Brunswick & Ontario 54
- 6.2 Design of Effluent Treatment Facilities for Intensive Salmonid Aquaculture 55
- 6.3 Projected Production of Phosphorus and Solids from Intensive Salmonid Culture Facilities 59
- 6.4 Projected Performance of Effluent Treatment Facilities 60

CANADIAN AQUACULTURE SYSTEMS

6.5 Management Strategies for Effective Effluent Quality Control . 68
6.5.1 Feed and Feeding Practices 68
6.5.2 Rearing Unit Design 68
6.5.3 Solids Settling Unit Design 70
6.5.4 Solids Removal and Disposal 71
6.6 Economics of Effluent Treatment in New Brunswick Smolt Production 73

7.0 EFFLUENT DISCHARGE GUIDELINES 77

8.0 PROJECT SUMMARY 79
8.1 Intensive Salmonid Culture Operations 79
8.2 Effluent Treatment Design 79
8.3 Management Strategies 80

9.0 LITERATURE CITED 82

APPENDIX I - Field Survey Questionnaire 87

APPENDIX II - Water Quality Data from Participating Fish Farms 89

APPENDIX III - Spearman's Correlation Matrices for Participating Fish Farms 91

APPENDIX IV - Effluent Treatment Facilities Data 96

APPENDIX V - Regression Analysis 98

1.0 INTRODUCTION

1.1 Aquaculture in New Brunswick

Aquaculture began in Canada over 100 years ago with the controlled propagation of a variety of sport fish species for stock enhancement programs (MacCrimmon 1984). Such operations were predominantly hatchery operations designed to supplement the recruitment and survival of fry. It was not until the 1950s, with the culture of oysters and trout in British Columbia, that commercial production of fish for human consumption began.

Following initial attempts to over-winter Atlantic Salmon in sea cages during the winter of 1978-79, New Brunswick's commercial salmon culture industry developed in the Bay of Fundy region during the early 1980s. Initially, a number of small operators were involved, however, by 1985 major players such as Sea Farms (Canada) Ltd. and Connors Bros. Ltd. also entered the industry. A number of factors, including increased awareness of aquaculture as a viable alternative source of fisheries products, technological advancement in culture techniques, and the suitability of the Bay of Fundy region for commercial-scale cage culture operations, have contributed toward the rapid growth of salmonid aquaculture in New Brunswick.

In 1979, the province had only one commercial operation, which produced 6.3 metric tonnes (MT) of Atlantic Salmon. By 1985 this had increased to 5 farms and total production reached 68 MT. In 1988, more than 40 active sea cage farms, principally located in the Fundy Isles area of the province, produced approximately 3600 MT of Atlantic Salmon and generated gross revenues of US $32 million. Furthermore, these operations employed about 170 people (Aiken and McMullun 1989). Production is expected to surpass 5000 MT by the early 1990s (Cook 1988).

In spite of these numbers, industry growth is being somewhat constrained by the limited availability of smolts for stocking into sea cages. Currently 21 hatcheries (2 government and 19 private) produce smolts in New Brunswick, however, 1989 represents the first production year for 8 of these operations. Of these 21 farms, 8 are industrial scale commercial smolt production operations, each capable of an annual production greater than 100,000 smolts.

1.2 Environmental Impact of Intensive Salmonid Aquaculture

In many types of commercial aquaculture, production practices must be highly intensive for an operation to achieve economic feasibility. In such systems, it is not unusual for the available water supply to be re-used in multi-pass facilities to attain the necessary production goals. Moreover, in aquaculture, there is a saying: "Fish don't pollute, but feed does!" As with all animals, feed is only partially utilized by the fish; the remainder is discarded into the water as soluble metabolic by-products and solid waste. Consequently, intensive culture practices can lead to substantial deterioration of water quality. Unlike the terrestrial farming of livestock, which often creates off-site pollution problems, the presence of unutilized feed and the metabolic waste products excreted by the fish foul the water and, therefore, the

system requires continuous flushing to maintain an acceptable culture environment (Wheaton 1977).

Nearly 20 years ago, Liao (1970a) stated that "The potential problem of pollutants discharged from a salmonid fish hatchery has long been overlooked. There is almost no literature on the subject." Today, however, the problem is well recognized and the issue of effluent quality has been a concern from an environmental perspective for many years. Aquacultural wastewater treatment is no longer viewed as an option in fish farming, it is considered to be necessary for the protection of the receiving water course and the assurance that water quality objectives are attained.

Nevertheless, while it is commonly accepted that rapid and gentle removal of the solid waste component of discharged effluent is essential, years of discussion and research have failed to produce appropriate technologies for effective and economical wastewater treatment at aquaculture facilities. In fact, Liao's statement, with minor modification, still applies today:

> The potential problem of pollutants discharged from a salmonid fish hatchery has long been *discussed*. There *remains* no *rationalized solution* on the subject.

Moreover, this problem is not limited to New Brunswick smolt production operations. In Aquaculture Magazine, Hopkins and Manci (1989) state that, industry-wide,

> "pollution-related problems in fish culture are on the rise. As the industry grows and expands, these problems will continue to intensify unless economically and scientifically sound solutions are discovered and applied."

Liao (1970a) classifies aquacultural waste products into three categories:

(1) chemicals and drugs employed for cleaning and/or control of diseases, parasites and aquatic weeds;

(2) bacteria and parasites which may be harboured in the facility and subsequently released; and,

(3) fish fecal matter and residual feed, and soluble metabolic products.

While the first two categories of pollutants are important to understanding the full impact of aquacultural discharges, for the most part they tend to occur relatively infrequently. Nevertheless, these issues must also be examined by the aquaculture industry -- ideally before they lead to problems similar to those currently facing the industry with respect to solids and nutrient discharges. In comparison, however, the discharge of fish fecal matter and residual feed is an ongoing occurrence at commercial, hobby, and R&D fish culture facilities. Moreover, since most salmonid aquaculture facilities are located on sites containing high-quality water resources, the solid waste component presents a serious pollution problem, especially when farm effluents are discharged to

sensitive cold-water receiving bodies. Conventional loadings of seven common fish farm pollutants are presented in Exhibits 1.1 and 1.2.

1.2.1 Suspended Solids Production in Intensive Salmonid Culture

Aquaculture-related pollution problems manifest themselves in various ways. The accumulation of solid matter on stream bottoms can be especially detrimental to aquatic environments. In fact, the Michigan DNR (1973) concluded that the total suspended solids load was the most significant problem caused by hatchery discharges. Since fecal and feed solids are predominantly organic matter, their oxidation depletes the dissolved oxygen concentration in the water and results in the release of dissolved nutrients. Moreover, these solid wastes support a diverse population of micro-organisms which also contribute to oxygen depletion, and which may be deleterious to other aquatic species. If left to accumulate to depths where bottom layers become anaerobic, noxious gases and other toxic compounds can form. Samuelsen et al. (1988) found that the gasses generated from fish farm sediment deposits consisted primarily of methane (70-90%), carbon dioxide (10-30%), and hydrogen sulphide (1-2%), all of which are toxic to fishes and other aquatic organisms.

Relative to phosphorus, waste solids production in intensive fish culture is less complex to model, and solids are substantially simpler to remove from discharged effluent. Due to periodic changes in feed formulations based upon feed ingredient costs, however, waste solids production is not necessarily predictable. Nevertheless, industry average production rates have been established for intensive trout culture which are sufficiently accurate for modelling.

Merican and Phillips (1985) report no significant correlation ($P>0.05$) between TSS output and fish size, and conclude that feeding rate, rather than fish size, is the primary determinant of solid waste production. Depending upon feed composition and digestibility (efficiency of utilization), waste solids production varies between approximately 200 kg and 1000 kg per metric tonne of fish produced (Westers 1989). A number of researchers suggest that 300 grams of waste solids per kilogram of feed added to the system is an acceptable industry average (Willoughby et al. 1972; Mudrak and Stark 1981; Zeigler 1988). This production rate is confirmed by Cho et al. (1985), who found waste solids production to range between 200 to 400 grams per kilogram feed. Westers (1989) indicates that levels below 200 gTSS/kg feed are unrealistic in commercial culture settings and that levels above 450 gTSS/kg feed are infrequent since they tend to be indicative of poor feed utilization and/or feed wastage. Moreover, since feed is the largest single cost factor in commercial trout culture, the latter quickly becomes uneconomical. For modelling purposes, a solids production rate of 300 grams TSS per kg feed is conventionally applied (Exhibit 1.1).

1.2.2 Phosphorus Production in Intensive Salmonid Culture

The addition of phosphorus to aquatic habitats can present serious, long-term pollution problems. Fortunately, from a biological productivity perspective, inorganic orthophosphate is the only form of phosphorus of

significance (Wetzel 1975), and the phosphorus component in fish feed which ultimately ends up in the receiving body of water is principally organic phosphorus bound within the solid waste particles (Persson 1988). As such, it is biologically unavailable in the water column.

Nevertheless, chemical and biological reactions can act to liberate phosphorus from bound particles, thereby enhancing primary productivity and eutrophication. In the water column, an exchange equilibrium is established between phosphorus in sediments and the water. Under aerobic conditions, this equilibrium is largely uni-directional toward the sediments. Once the sediment layer becomes sufficiently thick (deep), such that diffusion of oxygen to lower layers becomes limiting, anaerobic conditions develop. In the absence of oxygen, the equilibrium shifts toward the water column due to changes in redox conditions, resulting in the release of biologically available phosphorus compounds. Phosphorus mobilizing bacteria are also present, especially in highly organic sediments such as fish culture wastes, and serve to increase the pollution impact of phosphorus, although their impact is generally about 1/20th that of anaerobic chemical reactions (Wetzel 1975; Sondergaard 1988).

This biologically available fraction of phosphorus (and to a lessor extent, nitrites and nitrates) in fish farm discharges, contributes to the enhancement of primary productivity (i.e. increased populations of micro- and macro-algae), thereby promoting eutrophication of the receiving body of water (Trojanowski et al. 1985; Persson 1988). In Ontario, the Ministry of the Environment (1982) observed that the aquatic environment was substantially impaired in streams below discharges from trout farms as compared to sites immediately upstream of the farms. Detrimental effects were principally related to increases in the total number of benthic organisms, especially *Chironomidae* (midge) and *Simuliidae* (black flies), the stimulation of luxuriant plant and algal growth, and the accumulation of organic solids on stream bottoms. The Michigan Department of Natural Resources (1973) studied water quality below 9 salmonid fish culture facilities in the state and discovered downstream increases in the concentration of BOD, suspended solids, organic nitrogen, ammonia nitrogen, soluble ortho-phosphate, and total phosphorus. Liao (1970a) also reports similar upstream-downstream changes at aquaculture effluent discharge sites in Washington state.

Salmonid fishes have 3.8 to 4.5 grams of phosphorus per kilogram body tissue; the accepted average being 4.0 gP/kg tissue or 0.4%. Nevertheless, the dietary requirement for phosphorus is generally 0.7 to 0.8 percent feed weight, in spite of research results which indicate that experimental diets having phosphorus concentrations as low as 0.4% produce no detrimental effects to production and growth (Ketola 1985; Eskelinen 1986; Wiesmann et al. 1988). Many commercial diets, however, have phosphorus levels ranging between 1.1% and 1.8%. This excess phosphorus ultimately ends up in the receiving body of water since it cannot be utilized by the fish.

Merican and Phillips (1985) found that an average of 65.9% of dietary phosphorus is discharged in the solid fecal waste. Not all of this discharged phosphorus remains bound, however. EIFAC (1972) reports that up to 32% of the particulate phosphorus is solubilized within 2 days of discharge. Alternatively, field data show that, on average, 30% to 60% of all phosphorus discharged from salmonid fish culture operations is permanently retained in the sediment fraction

of the solid waste (Persson 1988). Variability is due to the feed brand and specific feed ingredients. For instance, phytin, a phosphorus compound in plant proteins, is poorly absorbed by fish, yet it is frequently included in fish feeds. Other sources of phosphorus, such as defluorinated rock phosphate, are better utilized by salmonid fishes and are less polluting (Ketola 1985). Based on usual ingredients, commercial diets tend to contain excessive quantities of phosphorus which are not required for optimum performance (Wiesmann et al. 1988).

The figures presented in Exhibit 1.3 simplify the utilization of phosphorus by salmonids to illustrate the potential pollution impact of excess dietary phosphorus. The numbers reveal that effluent phosphorus levels increase substantially with increased dietary phosphorus since fish have a limited phosphorus uptake capacity, which does not change with dietary level. Notice that a change in dietary phosphorus concentrations from 0.7% to 1.6% increases total discharged phosphorus four-fold.

Westers (1989) suggests that the average discharge of phosphorus from salmonid culture operations ranges between 1.5 and 25 kg P per metric tonne of fish produced. Castledine (1986) provides factors used to determine waste phosphorus production in intensive rainbow trout culture facilities. He indicates that, for every kilogram of feed added to the system, 5.4 grams of settleable and suspended phosphorus and 2.2 grams of dissolved phosphorus are discharged in the production effluent; a total of 7.6 grams of phosphorus per kilogram feed. The proportion of TP to DP is 71:29. Cho (1990) and Ketola (1989) suggest that 9 grams of phosphorus per kilogram of feed may be more a appropriate factor, and that the breakdown between solid and soluble forms approximates 67:33. Cho further adds that, at a minimum, 25% of all phosphorus in the effluent will be dissolved in solution. Castledine's factors are most frequently applied for effluent modelling (Exhibit 1.1).

Therefore, the production of pollutants in salmonid aquaculture is directly related to the input of feed to the culture system and can be estimated using the accepted feed factors as described by Castledine (1986), and presented in Exhibit 1.1. It should be noted, however, that feed quality, daily operations (i.e. feeding, cleaning, etc.), culture practices (i.e. stocking densities, water flow rates, general management techniques, etc.), and seasonal variation in standing crop biomass create fluctuations in the actual amount of wastes produced. Although effluent solids and nutrient concentrations in salmonid fish culture effluent are relatively dilute (see Exhibit 1.2), long-term cumulative problems may develop in receiving waters due to the high volumetric flow rates required by salmonid fishes (Liao 1970a).

1.3 Project Purpose and Objectives

In view of the wastes generated in salmonid fish culture, aquacultural effluents can potentially violate several provincial water quality objectives:

1) The average effluent concentration of total suspended solids should not exceed 5-10 mg/L and the concentration of total phosphorus in the receiving body of water should not exceed 0.05-0.10 mg/L to ensure that natural habitats are not destroyed by eutrophication.

2) The mass of solids produced may settle to form objectionable deposits in the receiving water course.

3) Dissolved phosphorus and nitrogen compounds may contribute to undesirable aquatic life or result in the dominance of nuisance species.

4) To a lesser extent, floating bacterial and/or algal mats and scum may become a nuisance.

5) If poorly designed settling ponds are used (as is currently the case at several operations), long detention times may cause warming of the discharged effluent during summer months, which may create a barrier to the migration of fish and aquatic life in the mixing zone of the receiving body of water.

Therefore, an effective means for reducing the solids content of the discharged effluent is necessary; however, the high volumetric flow rate, and the relatively dilute concentration of pollutants in the effluent, impose a unique constraint on effluent treatment. Westers (1989) reports that the concentration of phosphorus discharged from tertiary sewage treatment lagoons may be as much as ten times greater than that in untreated fish hatchery effluent. The total volumetric flow from salmonid hatcheries compounds the impact, however. Solbe (1988) suggests that the impact of untreated effluent from 1000 kilograms of fish is equivalent to the daily discharge of treated sewage from a city of 300,000 people. Consequently, treatment technologies must be highly efficient, yet they must also be economically feasible to install and operate (Liao 1970b).

The uniqueness of most fish culture operations has meant that standardized effluent treatment technologies have not been developed. Rather, treatment facilities tend to be custom-made for individual operations (Lindqvist 1986). Although custom design may continue to be the norm in this industry, with its diversity of facility designs and culture practices, a need nevertheless exists for the development of standardized design protocol.

Consequently, the purpose of this investigation has been to conduct applied research to identify standardized and cost-effective techniques for the design and implementation of appropriate wastewater treatment technologies and operating practices for both new and existing smolt production and salmonid fish culture facilities in the Province of New Brunswick. Within the scope of this investigation, the following objectives have been targeted:

1) Characterization of fish farming wastes on an industry-wide scale.

2) Evaluation of existing effluent treatment facilities.

3) Identification of primary constraints relating to the high-volume, low-concentration nature of fish farm effluents and identification of appropriate technologies for aquaculture wastewater treatment.

4) Assessment of the economics and cost structuring of aquaculture wastewater treatment facilities, including capital and operating expenses.

Exhibit 1.1:
Accepted factors used to determine waste production from salmonid fish culture facilities based upon feed consumption.

Pollutant	Factor (x feed weight)[1]
Total Settleable & Suspended Solids	.300[2]
Settleable & Suspended Phosphorus	.0054
Dissolved Phosphorus	.0022
Total Phosphorus	.0076
Settleable & Suspended Nitrogen	.0064
Dissolved Nitrogen	.0317
Ammonia	.0383

Source: Castledine (1986)
[1] Factors will vary with changes in dietary efficiency. These factors assume dry feed (10% moisture) with an average digestibility of 80% and a Food Conversion Ratio = 1.2
[2] Westers (1989)

Exhibit 1.2:
Average increases in pollutant concentrations at salmonid fish culture facilities during normal operations. All units in mg/L.

Pollutant	Average Increase	Range
BOD	5.36	0.12 - 36.5
Ammonia	0.532	0.00 - 2.55
Nitrite	1.676	0.045 - 3.1
Phosphate	0.077	0.01 - 0.26
Suspended Solids	7.0	0.0 - 55
Settleable Solids	3.5	0.0 - 35

Source: Liao (1970a)

Exhibit 1.3:
The fate of dietary phosphorus based upon % phosphorus in feed, and assuming that fish utilize 0.4% phosphorus by body weight. This oversimplifies the issue, however, it is intended to illustrate the fate of excess dietary phosphorus.

% P in Feed	kg P/1000 kg Feed	kg P Retained by Fish	% P Retained by Fish	kg P Discharged in Effluent
0.7	7.0	4.0	57.0	3.0
1.1	11.0	4.0	36.0	7.0
1.6	16.0	4.0	25.0	12.0

2.0 TECHNOLOGIES FOR AQUACULTURE EFFLUENT TREATMENT

Due to the high volume of process water associated with intensive salmonid fish culture operations, and the concomitant low concentration of particulate and dissolved pollutants, effluent treatment practices are generally limited to primary treatment technologies; that is, the removal of particulate matter (Persson 1988). Secondary (i.e. biological filtration, aerated lagoons, carbon absorption) and tertiary (i.e. chemical coagulation, nitrification-denitrification, ion exchange, etc.) treatment technologies have received only limited application in aquaculture, and tend to be limited to highly-specialized applications.

The removal of solid material from wastewater streams and the selection of appropriate treatment technologies is governed by (1) particle size, (2) specific gravity, and (3) strength, or shear resistance, of the particulate matter. An initial requirement, therefore, in selecting an appropriate solids separation technique for any application, is identification of the properties of the material to be separated.

Wastewater solids are routinely classified into four categories, based upon particle size: soluble (<0.001 μm); colloidal (0.001 - 1.0 μm); supra-colloidal (1.0 - 100 μm); and settleable (>100 μm). The total suspended solids (TSS) component of a wastewater stream is determined by filtration of a sample of the wastewater through a 0.45 μm membrane filter, and measurement of the dry weight of the sample in mg/L. Settleable solids are further defined as that portion of the TSS which will settle, in quiescent conditions, within one hour due to gravity alone (Sundstrom and Klei 1979).

Numerous technologies, most of which have originated in municipal and/or industrial wastewater treatment applications, have been applied in aquaculture for solids control. The UMA Engineering Ltd. report (1988) describes the use of several of these methods in fish farming, including gravitational separation, screening, and filtration, among others. Consequently, similar descriptions will not be presented here. Alternative technologies, including peat bed filtration, flocculation through addition of coagulants, and nutrient removal via plant biomass uptake, are described by Parjala (1984). Stechey (1987) discusses the use of static screen, vibrating screen, centrifugal screen, micro-screen, and compact sedimentation units.

Peat bed filtration is conducted in earthen ponds having a 30 - 50 cm thick layer of peat overlaid on a gravel percolation bed. While the specific absorption of peat varies with the species of peat, its level of humification, and various physical and chemical properties, a rule of thumb states that up to 200 grams of phosphorus can be removed per cubic meter of peat. In spite of its capacity for phosphorus absorption, commercial-scale application is limited to only the smallest farms due to total flow limitations. Similarly, coagulation also tends to be inefficient for aquacultural application, again due to the high volume, low concentration nature of the wastewater stream. Moreover, the cost of chemical coagulants would be relatively high and large contact chambers would be required (Parjala 1984).

Static screens offer the advantages of high volumetric capacity, compact size and portability, relatively long screen life, production of a relatively concentrated solids fraction, and the addition of dissolved oxygen to the wastewater stream. In aquacultural applications, however, the specific gravity of the solids to be clarified is often too low to adequately permit their collection and discharge from the units. Moreover, most high-volume static screens require a pressurized feed source, resulting in an added energy component (Dorr-Oliver 1982). As well, on-site testing with low-head gravity-feed screens has revealed that undigested plant materials (presumably fibre from feed ingredients) and the relatively sticky fish fecal material cause blinding of the screen, resulting in the need for frequent cleaning (Stechey 1987).

Consequently, it is generally agreed that, for efficient and effective removal of solids from fish farm effluents, most existing filtration and screening technologies tend to be impractical from either a functional or economical approach, or both. Notwithstanding that some commercially available treatment units have an application in specific aquaculture operations, sedimentation practices (i.e. gravity separation) tend to be most widely applicable in commercial salmonid culture. Sedimentation basins require no energy input, are relatively inexpensive to install and operate, require no specialized operational skills, and can be easily incorporated into both new and existing facilities.

3.0 SEDIMENTATION TECHNOLOGIES FOR AQUACULTURE WASTEWATER TREATMENT

3.1 Fundamental Concepts of Sedimentation

When a liquid containing particulate matter is placed into a relatively quiescent state, those particles having a specific gravity greater than that of the liquid begin to settle. This principle has been applied for generations as a means of clarifying wastewater streams. Depending upon particle size and density, and the physical characteristics of the wastewater medium (water), the sedimentation process can be defined as either discrete (Class I), hindered or flocculent (Class II), zone (Class III), or compression settling (Class IV). These processes are defined in Exhibit 3.1.

A rule of thumb states that, at total suspended solids concentrations below approximately 500 mg/L (0.05% solids), sedimentation is typically discrete (Camp 1946). Discrete settling particles maintain their size and shape in a dilute suspension, and have little tendency to adhere upon collision. Each discrete particle has a constant settling velocity, which is independent of that of other particles. Flocculation tends not to occur due to the remote likelihood of chance collisions between particles in such dilute concentrations. Therefore, in salmonid fish culture effluents, it is reasonable to assume that settling is discrete.

Exhibit 3.1:
Suspension classes and their settling characteristics.

Class I Suspensions - Discrete

Definition: Dilute suspensions of non-flocculent particles that settle out of suspension unhindered by the presence of other particles.

Behaviour: Sedimentation rate is governed only by the surface area of the sedimentation basin.

Class II Suspensions - Flocculent

Definition: Dilute suspensions of flocculent particles which, upon collision, coalesce and settle at rates greater than did the parent particles.

Behaviour: Sedimentation rate governed by (1) surface area of sedimentation basin, (2) concentrations of suspensions, and (3) depth of basin.

Class III Suspensions - Zone

Definition: Suspensions of high concentration in which particles settle in a fixed position relative to each other in a regime referred to as hindered or zone settling. Particles may be flocculent or non-flocculent.

Behaviour: Sedimentation rate governed by (1) surface area of sedimentation basin, (2) concentration of suspension, (3) solids loading, and (4) depth of basin.

Class IV Suspensions - Compression

Definition: As particles accumulate in layers on the bottom of the basin, each layer of solids provides support for those layers above and the solids undergo compressive stress which compacts the layers further.

Behaviour: Sedimentation has already been achieved prior to this stage; concentration of the settled solids is governed by (1) the sludge depth, and (2) the retention time in this compressive zone.

Source: Adapted from Sundstrom and Klei (1979); Rich (1980)

Under the force of gravity, a particle accelerates downward through the water column until the gravitational force comes into equilibrium with the opposing frictional fluid drag force. When these opposing forces become balanced, the particle settles at a uniform velocity, which is referred to as the terminal settling velocity (Vs).

All continuous flow settling basins are comprised of four zones according to function (Exhibit 3.2). The inlet zone serves to uniformly distribute the suspension over the entire cross-section of the basin. Sedimentation occurs in the settling zone and, upon removal from the water column, the solids accumulate in the sludge zone. The clarified liquid is generally collected over the entire cross-section of the basin at the outlet zone and is discharged.

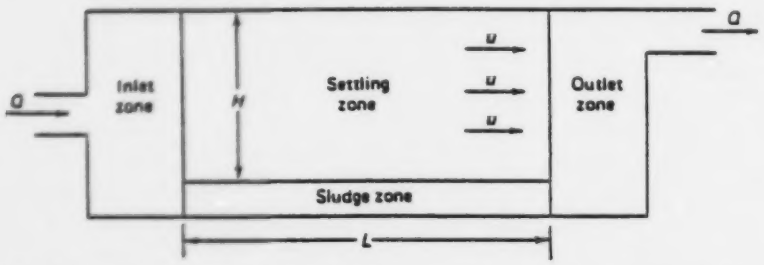


Exhibit 3.2: Four principle zones of a rectangular continuous flow sedimentation basin.

Sedimentation theory is most easily defined using an "ideal basin," for which the following assumptions apply:

(1) the direction of fluid flow is horizontal and the fluid velocity is constant at all points in the settling region;

(2) the concentration of suspended particles of each size is uniformly distributed over the vertical cross-section of the tank at the inlet end; and,

(3) all particles which settle to the basin floor remain permanently removed from the suspension.

In a rectangular ideal basin, the settling paths of all discrete particles are straight lines defined by the vector sum of the horizontal velocity component (U) due to fluid flow across the basin and the vertical settling velocity (Vs) of the particle due to gravity (Exhibit 3.3).

All particles with the same settling velocity will move in parallel paths. Under ideal conditions, a particle which starts at the top of the inlet zone and settles to the tank floor at the junction of the outlet zone during its theoretical detention period represents the tank discharge per unit surface area. This is defined as the tank overflow rate, which represents the unit volume of water flow per unit time divided by the unit area of the settling basin (Vo = Q/A); it is the average upflow velocity of the basin.

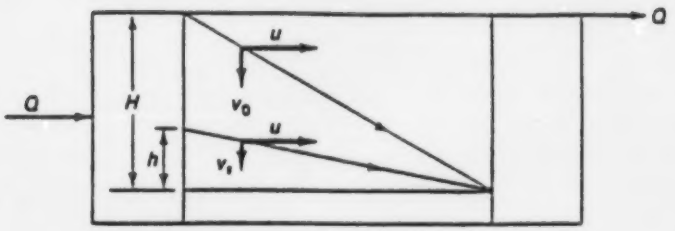


Exhibit 3.3: Settling paths of discrete particles in a rectangular sedimentation basin.

Any particle with a settling velocity (Vs) greater than the overflow rate (Vo) will settle out of suspension. Other particles, for which Vs < Vo, will be removed in the ratio Vs/Vo, depending upon their vertical position in the tank at the inlet (Hazen 1904). This fractional removal (Fx) is defined by the equation:

$$Fx = \frac{Vs}{Vo} = \frac{Vs}{Q/A}$$

The settling velocity analysis of a suspension may be presented as a cumulative distribution curve (CDC), with the ordinate (Cr) representing the fraction of particles (f_o) in the suspension with settling velocities less than the corresponding settling velocity on the abscissa. [Note: This concept is applied in the settling curves for those farms included in the study; see Exhibit 4.7]. The fraction of particles removed completely then is equal to 1 - f_o; (i.e. those with Vs > Vo). The fractional removal of those particles with Vs < Vo is defined by the integral:

$$\int_0^{f_o} \frac{Vs}{Vo}\, df$$

The overall removal (F) of particles in suspension in an ideal basin is defined by the sum of the terms for settling velocities greater than and less than Vo, the tank overflow rate:

$$F = (1-f_o) + \frac{1}{Vo} \int_0^{f_o} Vs\, df$$

Therefore, the removal of suspended matter by sedimentation in an ideal basin is a function of the basin surface area and is independent of tank depth. Moreover, removal is a function of the overflow rate (Vo) and, for a given discharge, is independent of retention time.

3.2 Factors Influencing the Design of Sedimentation Basins

Sedimentation processes in actual basins are much more complex than the process described for an ideal basin. In an actual tank the behaviour of the settling particles is altered by turbulence and scour, which tend to re-suspend particles; and by velocity gradients, density currents and short-circuiting, which give rise to mixing and reduced removal efficiency.

3.2.1 Tank Velocity, Turbulence & Scour

In an ideal basin, the sedimentation of discrete particles is a function of overflow rate, and is independent of tank depth and retention time. In theory then, economics would suggest the use of infinitely shallow basins. Real basins, however, are restricted to minimum tank depths based upon the maximum allowable tank velocity (Uc) that can be maintained without excessive scour. In any basin of fixed dimensions, and for a given overflow rate, the tank velocity varies inversely with tank depth.

Unlike ideal basin theory, tank velocity is not uniform over the entire cross-section of the basin. Due to boundary layer drag forces, horizontal fluid flow is quickest in the centre of the tank near the surface, and slowest near the tank walls and floor. Even in the best designed settling basins, the Reynold's number (Re) will approximate 2×10^3 to 2×10^4, however, laminar flow conditions exist at $Re \leq 1500$ to 2000. Therefore, flow in settling basins is typically in transition or turbulent, which results in the rapid and continuous mixing of the fluid.

Since most particles remain undisturbed once they settle to the floor of the basin, the effect of turbulence is limited to a delay in the sedimentation process. This can be compensated for by lengthening the sedimentation basin in accordance with the turbulent flow characteristics. In general, since an increase in tank velocity results in increased turbulence, faster flowing tanks must be longer, or of greater diameter, than slower flowing tanks to comparably clarify the same wastewater stream.

Therefore, to achieve the efficiency of removal projected by theoretical basin design, it is necessary to compensate for turbulence by increasing the surface area of the settling basin. Compensation can be readily achieved by applying the concepts presented by Fair and Geyer (1958). Using ratios based upon sedimentation theory, a table of scale-up factors was compiled to enable designers to compensate for turbulence by adjusting the overflow rate in the principal design equations (Exhibit 3.4).

For example, assume that one is working with a settling basin of "good" design (i.e. proper inlets, outlets, flows, area, etc.), and that a design overflow rate of 40 $m^3/m^2/d$ (0.046 cm/s) has been applied and, furthermore, that this overflow rate is projected to yield 75% solids removal. The data in Exhibit 3.4 indicate that, in reality, the performance overflow rate is equal to 68 $m^3/m^2/d$ (0.079 cm/s); i.e. 40 x 1.7. Consequently, the performance efficiency will be less than the design efficiency; the extent of the reduction being dependent on the shape of the solids settling curve. The net result is a reduced, but more accurate calculation of the removal efficiency of the basin. When applying these scaling factors, however, the characterization of basin

performance necessitates judgmental assessment, based upon the net sum of all design considerations for both new and existing basins.

Exhibit 3.4
Ratios of required to theoretical surface areas of settling basins and of actual to theoretical settling velocities of particles at different removal efficiencies.

Basin Performance	Removal Efficiency (%)					
	70	75	80	85	90	95
Very Good	1.3	1.5	1.8	2.2	2.7	3.6
Good	1.4	1.7	2.0	2.5	3.2	4.8
Poor	1.7	2.0	2.5	3.2	4.4	6.9
Very Poor	2.3	3.0	4.0	5.9	10	19

Source: Adapted from Fair and Geyer (1958)

The re-suspension of settled particles by shear forces generated along the sludge surface by the horizontal flow of water through the basin is termed scour. Scour reduces sedimentation efficiency by stirring up the settled particles and reintroducing them to the water column. Camp (1946) defined the critical flow velocity (Uc) necessary to initiate scour of settled particles:

$$Uc = \sqrt{\left(\frac{8B}{f}\right)(g)(s-1)(D)}$$

where:
- Uc = critical scour velocity (m/s)
- B = constant = 0.06
- f = friction factor (approx. 0.024)
- g = gravitational acceleration (m/s^2)
- s = specific gravity of particles (approx. 1.005)
- D = mean particle diameter (m)

From this equation, it is evident that the critical flow velocity for commencement of scour is independent of tank size and depth. The governing factors are the friction factor and the mean size and specific gravity of the particles. For aquacultural waste solids ranging from 0.25 to 1.5 mm in diameter, approximate scour velocities equal 1.6 to 3.8 cm/s. This is in agreement with Parjala (1984) who recommends a maximum horizontal fluid flow rate of 2 - 4 cm/s in aquacultural settling basins. Conversely, Boersen and Westers

(1986) concluded that horizontal flow velocities between 10 and 40 cm/s are required to prevent fecal and waste feed solids from settling in production tanks.

Dobbins (1944) determined that since solids removal is not independent of tank depth as indicated in ideal settling theory. The effect of depth is, nevertheless, quite small. On average, a 50% reduction in depth will result in approximately only a 5% decrease in removal of discrete particles. A 50% decrease in volume due to reduced depth, however, can be compensated for by a 5% increase in volume via increased surface area (Camp 1946). Thus, as economy dictates, the tank depth should still be maintained as shallow as possible, provided that scour-related problems do not arise.

3.2.2 Short-Circuiting & Tank Stability

Fluid flow through an ideal basin approximates plug flow, which means that there is no variation of lateral velocity over the cross-section of the tank. That is, a cross-section of water entering the settling zone from the inlet zone travels as a solid body throughout the length of the tank. Displacement is steady and uniform, and each unit volume of fluid is detained for the theoretical retention time of the basin, R_t = Vol/Q.

In reality, however, a portion of the flow exits from the tank after a shorter interval than the theoretical retention time while some of the water is retained longer. Short-circuiting is inherent to all tanks due to varying tank velocities in different stream paths caused by thermal-, density-, eddy- and wind-induced currents.

When the velocity of water entering the basin is too great, eddy currents are established by the inertia of the flowing water and mixing results. In large basins with long retention times, non-uniform heating of the water by the sun can result in vertical convection currents. Density currents typically occur when fluids of differing densities are combined in a quiescent tank or pond. The heavier fluid settles to the bottom of the basin and flows quicker than the lighter, top fluid. Fluid density differences may result from differences in temperature (solar heating), salinity, or suspended solids concentration. In most settling basins, however, fluid flow is generally sufficiently turbulent to disrupt density currents.

Wind shear over large tanks and ponds can create substantial surface currents which cause serious short-circuiting. The surface drift current is an almost constant ratio of the wind speed at 10 metres and this ratio varies minimally between researchers, and with Reynold's number (Plate 1970). A value of 1% to 3% of the 10 metre sustained wind speed is typical. Therefore, a wind speed of only 180 cm/s (approx. 6.5 km/hr) can induce a surface current with a speed of approximately 3.6 cm/s, which is of similar magnitude to conventional tank velocities.

Short-circuiting can also result from the presence of dead zones in a settling basin, which most commonly result from improper design of inlet and outlet structures (see Section 3.2.3). Dead zones are regions within a basin in

which the liquid plays little or no part in the displacement through the tank. In fact, this occurrence can be readily observed on inappropriately designed basins during winter months. Where water flow is slowest (usually around pond edges or behind baffles and booms) the surface of the basin freezes over. Where flow is swift (such as along the direct line between point source inlet and outlet pipes), open water remains. This results in an effective tank volume, and area, which is less than actual tank dimensions. Consequently, a percentage of the influent stream passes through the basin in a shorter time than the theoretical detention time while some water remains in the basin for a longer time.

Thus, the net effect of short-circuiting on sedimentation processes is reduced efficiency. The influent flow rate to any settling basin is tuned to the basin overflow rate (Vo) and is relatively constant, however, short-circuiting streams of quicker flow have an overflow rate which is greater than the design rate. As a result, any particles in that stream having a settling velocity less than the stream overflow rate, but greater than the basin overflow rate, will not settle as they otherwise would have. Conversely, slow moving or stagnant areas must also exist, which further reduce the effectiveness of the settling process. Control of short-circuiting, therefore, is dependent upon dissipation of inlet velocity, protection of basins from wind shear and uneven heating, and reduction of density currents. Foremost, however, proper inlet and outlet design is critical for minimizing short-circuiting in settling basins.

3.2.3 Inlet & Outlet Design Considerations

As discussed, improper inlet and/or outlet design can result in short-circuiting and reduced sedimentation efficiency. Placing a single pipe at each end of a basin is the simplest design for inlet/outlet structures and, unfortunately, it is perhaps the design most frequently used in aquaculture today. This type of point-source inflow and outflow produces extremely poor flow characteristics for sedimentation. Short-circuiting is severe as the influent stream flows directly through the basin, at high velocity, toward the discharge pipe. Consequently, a large portion of the fluid passes through the basin in a matter of minutes, although the theoretical detention period may be a matter of hours. To be effective, the design of inlet and outlet structures must address the specific function and constraints of each process.

Inlet Design. When designing inlet structures, Ingersoll et al. (1956) suggest that the following factors must be considered:

(1) The influent stream should be introduced evenly across the entire cross-section of the settling zone.

(2) All flow through the settling zone should begin in even, horizontal paths.

(3) The influent velocity to the settling zone should be slow enough to prevent excessive turbulence and mixing.

The influent to a settling basin usually flows through a pipe or channel which is smaller in cross-section than the basin. The flow, therefore, must diverge upon entering the inlet zone, often producing separation and turbulence in the process. A number of inlet structures have been designed to distribute the influent flow to a settling basin so that the above-listed factors are satisfied. Giles (1943) presents a thorough historical review of such inlet designs. Those inlet designs which are most inappropriate, and which should not be used in settling basins, are illustrated in Exhibit 3.5.

Screen-type, or orifice-plate, baffles have also been applied to achieve complete flow dispersion over the entire width and depth of settling tanks. Fouling of the screen, however, often prohibits the use of such baffle systems with many waste streams. Envirotech Corp. developed and marketed the Modular Energy Dissipating Feedwell (MEDF), a honeycomb of small tubes mounted across the basin inlet. The honeycomb creates a laminar flow pattern with uniform velocities across the inlet (US EPA 1975). Although effective in distributing the inlet flow, serious plugging of the tubes led to discontinued use of the design.

Submerged weirs, extending across the entire width of a basin, have been found to provide an optimal balance between practicality and flow characteristics for sedimentation. The first submerged weir (Exhibit 3.6) was introduced by Hubbel (1934). Hubbel's design utilizes an upward, diverging flow to the weir crest which greatly reduces flow velocity. The submergence of the weir serves to reduce velocity even further. As well, this weir features a wide, goose-neck crest, which is effective in utilizing any residual approach velocity to distribute the fluid over the vertical depth of the basin. This type of weir is highly effective in distributing the flow over the entire cross-section of the basin with a minimal inlet velocity.

A simplified yet effective version of Hubbel's weir is now commonly used to introduce wastewater streams into sedimentation basins (Exhibit 3.6). Flow enters the settling zone from a header tank at the water level of the settling basin. To smooth the flow, the weir crest, like Hubbell's goose-neck, is typically 30 to 60 centimetres wide and has chamfered edges. The top of the weir should be submerged approximately 15% of the basin depth.

Outlet Design. The discharge of water from settling basins has changed little over the years. Traditionally, an outlet weir extends across the width of the basin at the end opposite the inlet. In circular tanks, the outlet weir extends around the outer periphery; the inlet is at the centre. Clarified effluent overflows into the weir trough and is discharged. The weir rate (volume of water discharged per unit length of weir per unit time) governs the length of the outlet weir. It is critical that the weir edge be level to assure a uniform discharge rate across the entire weir length.

For weirs which are long in relation to the flow (i.e. having a low weir rate), a saw-toothed or V-notch edge is necessary for uniform discharge along the weir length (Fair and Geyer 1958). Such low-flow systems, however, are virtually non-existent in intensive salmonid culture operations. Conventional municipal wastewater treatment design standards recommend that weir rates not exceed 186 -

248 m^3/d per metre length of weir (ASCE 1959; US EPA 1975). For aquacultural operations, where the solids component of the effluent tends to be heavier and more viscous than conventional municipal wastes, a weir rate of 372 $m^3/d/m$ has been recommended for design purposes (Mudrak 1981).

Caution must be exercised in designing outlet weirs due to the updraft effect generated by such structures, as depicted by the flow net diagram in Exhibit 3.7. As the water approaches the outlet, the horizontal flow velocity increases due to a reduction in cross sectional area and the lifting velocities of stream lines flowing toward the surface weir permit the escape of solids. This is quite evident to the eye at overflow standpipe discharges in tanks, raceways and settling basins. As a result, a certain portion of the tank volume becomes ineffective for settling since suspended particles entering this section become entrained in the effluent flow. The ineffective volume is defined by a concave arc, which extends from a point at the surface of the basin upstream of the weir to a point below the weir, but not necessarily penetrating the full depth of the basin.

Mohlman et al. (1946) developed the following equation to calculate this ineffective volume in a settling basin:

$$\textit{Ineffective Volume} = k \left(\frac{q^2}{V_s^2} \right)$$

where: k = constant = 0.134
q = weir rate ($m^3/d/m$)
Vs = settling velocity of particles (m/d)

This equation shows that the magnitude of the entrainment effect is proportional to a ratio of the weir rate to settling velocity. Most importantly, however, this is a quadratic equation, meaning that should the weir rate double, the ineffective volume will increase four-fold! Consequently, for every unit increase in the weir rate (q), the corresponding decrease in settling efficiency is disproportionately greater.

Ingersoll et al. (1956), however, contest the value of k, the constant in the above equation, stating that the only proper way to determine the magnitude of entrainment is to characterize the flow net in each specific application. Fortunately, for tanks which are long relative to their width (as is generally the case in aquaculture), the entrainment effect is confined to an upstream distance equivalent to only about 1 to 2 multiples of the basin depth. Since the updraft effect of an outlet weir reduces the effective length of a settling basin, proper design requires that settling basins be lengthened proportionately to compensate for this reduced efficiency. An additional length requirement of 1.5 to 2.0 times tank depth is appropriate in most cases. Nevertheless, weir length should be maximized in all applications.

3.2.4 Principal Design Considerations

In summary then, for the removal of solids from aquacultural effluents, sedimentation basins should be designed with the following factors in mind:

(1) Overflow rate (Vo), that is, the settling velocity of the smallest particles to be theoretically 100% removed, must be the foundation of basin design.

(2) Detention periods are, of themselves, immaterial; in spite of current industry guidelines in many jurisdictions which still state retention times (Daley 1989). The detention periods result from the design and are <u>not</u> a basis for design.

(3) Basin depth should be as shallow as possible, providing that scour does not interfere with performance.

(4) Turbulence should be compensated for in basin design equations.

(5) Inlet and outlet structures should be specifically engineered in accordance with the characteristics of the basin dimensions and water flow rates.

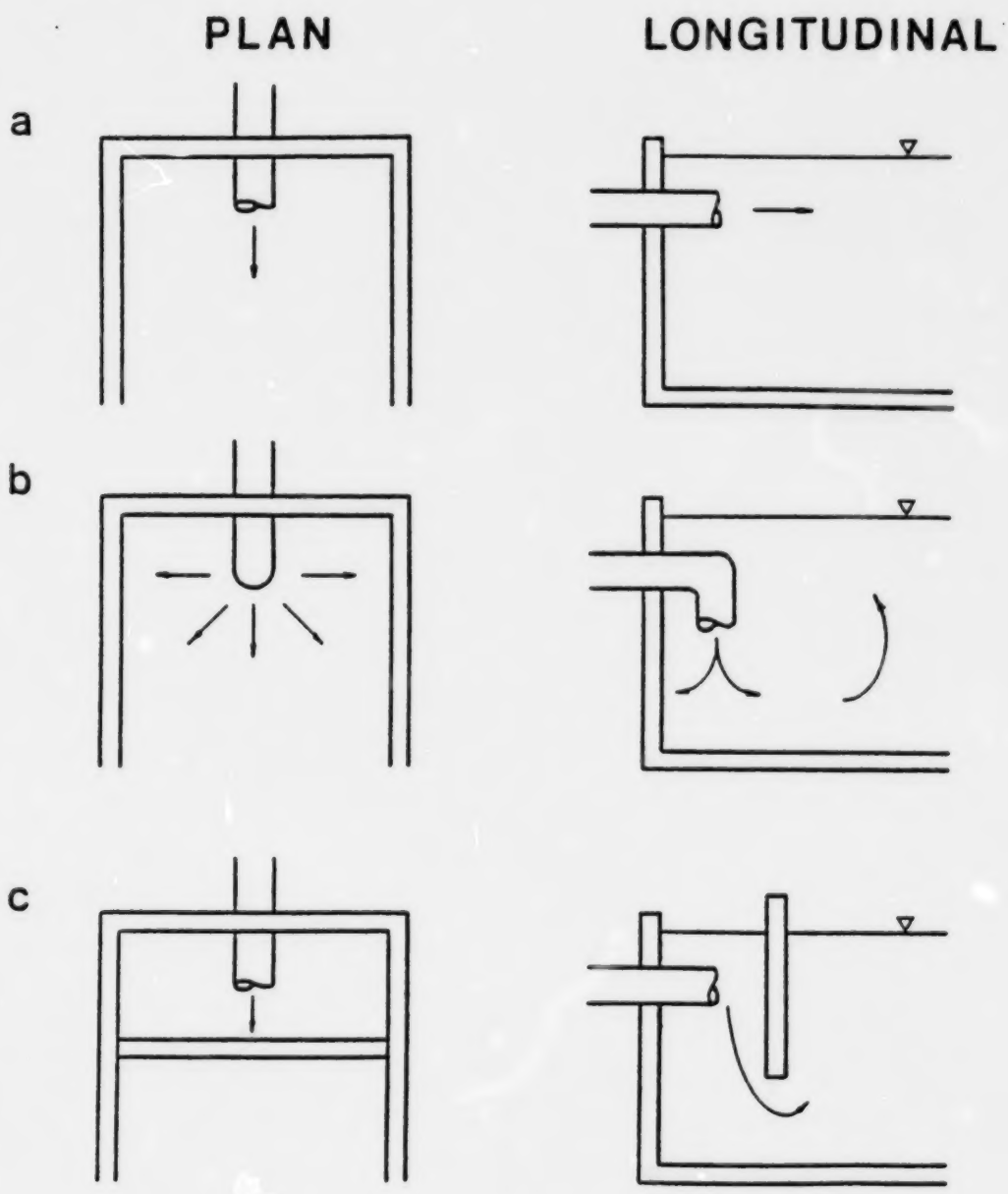


Exhibit 3.5:
Examples of inlet structures which are inappropriate for effective introduction of wastewater into settling basins. a. Straight pipe. b. Downward elbow. c. Straight pipe with target baffle.

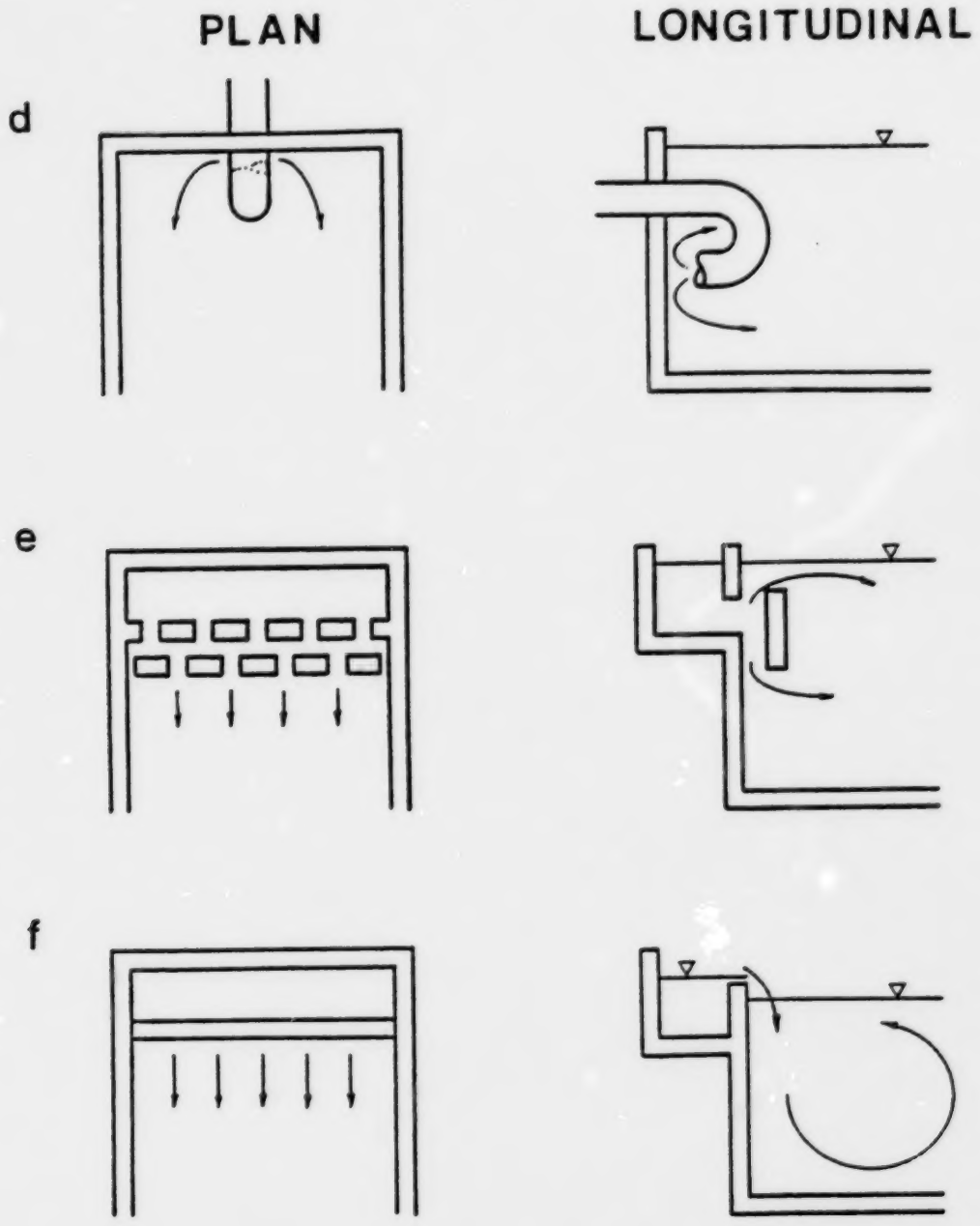


Exhibit 3.5: (cont'd)
Examples of inlet structures which are inappropriate for effective introduction of wastewater into settling basins. d. Reversing-flow. e. Multiple channels with target baffles. f. Free-fall weir.

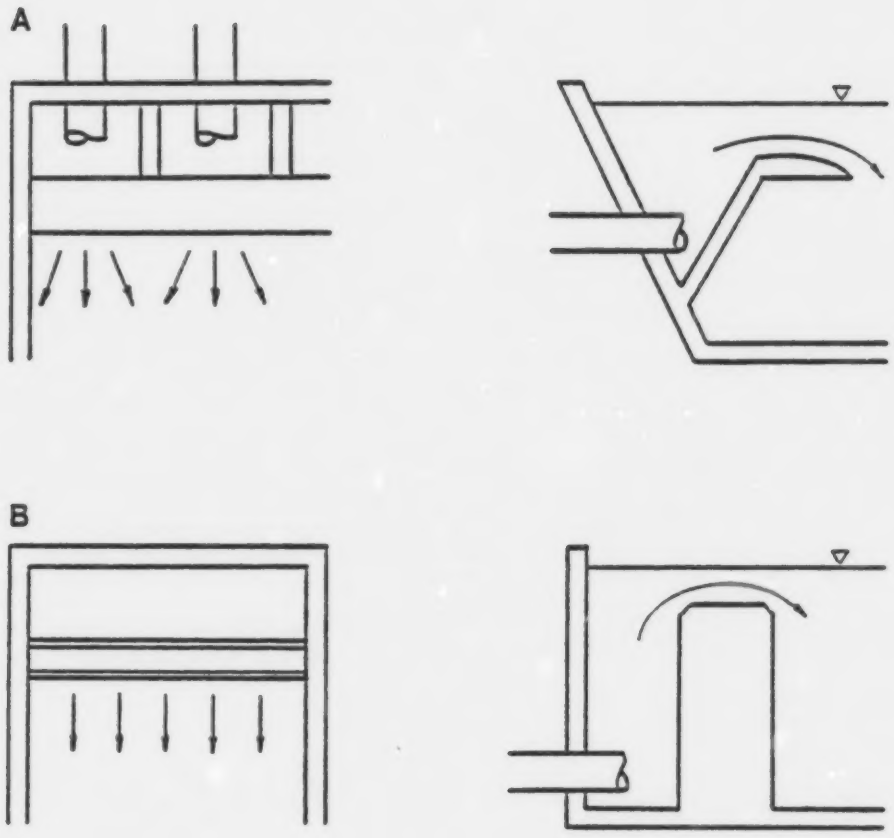
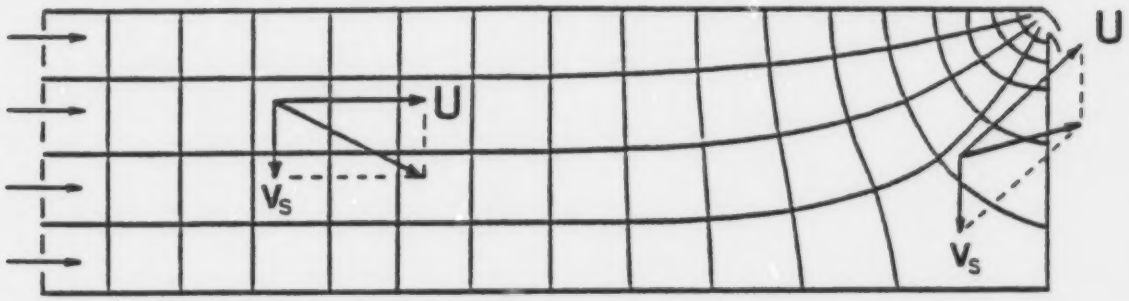
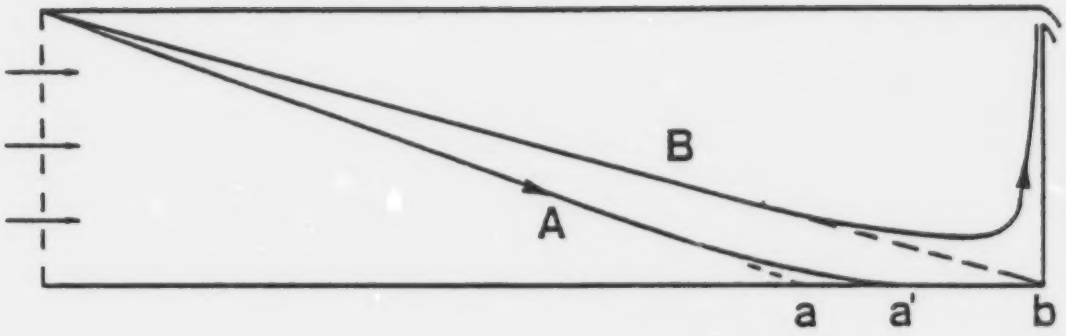


Exhibit 3.6:
Inlet structures designed for effective introduction of wastewater streams into settling basins. A. Hubbel's submerged goose-neck weir. B. Submerged wide-top weir with chamfered edges.



FLOW NET



PARTICLE SETTLING PATHS

Exhibit 3.7:
Two-dimensional representation of outlet weir effects on the fluid flow net and on particle settling paths in a rectangular settling basin. The updraft effect increases the required basin length for settling of particle A from a to a'. Particle B should settle at point b, however, it becomes entrained in the effluent and is discharged.
Source: Adapted from Ingersoll et al. (1956)

4.0 CHARACTERIZATION OF AQUACULTURE OPERATIONS & EFFLUENTS

4.1 Purpose & Objectives

Proper engineering design is essential if aquacultural wastewater treatment facilities are to be effective. Too often, facility design is based upon conventional municipal wastewater treatment design, and the specific characteristics of fish hatchery effluents are not considered. Waste characteristics, however, are the most important factor governing engineering design. Mudrak and Stark (1981) report that the solids component of aquaculture effluents is denser, faster settling, and tends to form a heavier, more viscous sludge than domestic municipal wastes. When these unique characteristics are not considered in facility design, the resultant treatment unit is typically oversized, expensive, and inefficient.

Therefore, settling analyses of the solids component of the wastewater stream must be an integral part of the design process. Surprisingly, however, in the intensive salmonid aquaculture industry, a comprehensive compilation of effluent solids sedimentation data have yet to be compiled and, consequently, the relatively poor performance of effluent treatment operations at such facilities should come as no surprise.

Since a wide variety of particle shapes and sizes exist in most suspensions, calculation of the settling velocity of discrete particles based upon Stokes' Law, or other theoretical equations, is impractical. By conducting a settling analysis of the suspension to be clarified, however, the overall gravitational removal of particles from suspension can be determined for any given overflow rate. The procedure for analysis of suspensions has been somewhat standardized, and is described by several authors (Camp 1946; Fitch 1957; Al-Layla et al. 1980).

Geometric models, although useful in evaluation of hydraulic short-circuiting, cannot be used to measure settling characteristics. Instead, a settling column having an inside diameter greater than 13 cm is required; narrower columns are not reliable due to boundary layer resistance introduced by column walls. To avoid extrapolation of data, the depth of the column should be greater than the depth of a full-scale settling basin in the desired application. Sample ports, where an aliquot of the suspension can be drawn off, are spaced along the side of the column.

Three additional components of fish culture processes must also be assessed in the quest for appropriate aquaculture wastewater treatment systems: (1) analysis of pertinent water quality parameters throughout the culture facility; (2) the design and layout of culture facilities; and (3) standard management practices. The field portion of this investigation was designed to collect these data from commercial and provincial fish culture facilities throughout New Brunswick.

By simultaneously collecting production, facilities design, and water quality data, answers to several key questions can be obtained.

Q. WHAT is the impact of intensive land-based fish culture operations on water quality?

Q. WHICH production and facilities design factors contribute to the deterioration of water quality?

Q. HOW do the suspended solids behave under quiescent settling conditions?

Q. WHAT are the values of critical design components at existing effluent treatment facilities on fish farms and how are they related to the operating efficiency of these facilities?

Several previous studies have addressed the first question, however, it is the inter-relationship of answers to all four questions that makes this investigation unique and, furthermore, that will provide practical solutions for effluent management at fish culture facilities. Such answers will identify those variables which facilitate the segmentation of fish culture operations into discernible groups, based upon similarities in design and operating characteristics of the production unit. Past research has already shown that different farms can have substantial differences in solid and dissolved waste output (Ont. Min. of Environment 1982; Hilton and Slinger 1984; Merican and Phillips 1985). The compilation of a broad data base will enable the design of effective effluent treatment facilities based upon the characteristic traits of a given farm and the associated production features of the group to which that farm belongs.

Protection of the receiving water course must be a prime consideration in the design, construction, and operation of any aquaculture facility. Standardization of design criteria for the various types of culture facilities, and the development of proper management practices, will enhance the responsible use of aquatic resources by aquaculturists. Moreover, standardization of design principles will provide confidence to decision-makers in their evaluation of aquacultural wastewater treatment facilities, thereby permitting the identification of the underlying cause(s) of non-compliance; i.e. whether the problem hinges on a design factor or poor management practices.

4.2 Field Survey & Water Quality Sampling

A field monitoring program was developed during the autumn of 1989 through the cooperative efforts of The New Brunswick Department of the Environment (DOE), the N.B. Department of Fisheries and Aquaculture (DFA), and the New Brunswick Salmon Growers' Association (NBSGA). The survey goal was to schedule site visits to 11 commercial and government salmon smolt production operations throughout New Brunswick. The field portion of this investigation included:

- contacting fish farm operators and scheduling site visits;
- collecting production and operations data from respondent farm managers;
- conducting on-site sedimentation tests at fish culture facilities;

- collecting representative water chemistry samples and delivering samples to the DOE laboratory for nutrient analyses; and
- conducting suspended solids filtration analyses in the DOE laboratory at Fredericton.

Data collection was comprised of three principal categories:

A. PREDICTOR VARIABLES
   (1) Production and Management Variables

B. RESPONSE VARIABLES
   (2) Water Chemistry Variables
   (3) Solids Settling Variables

Predictor variables consist of those production and management practices, and specific facilities design features, which characterize the fish culture operation. These data were collected to illuminate potentially causative agent(s) of deteriorating water quality. Response variables are those parameters of primary concern from a water quality and effluent management perspective. A standard data sheet was compiled to facilitate the collection of similar data from all operations included in the study (see Appendix I).

4.2.1 Predictor Variables

Predictor variables were divided into three groups to facilitate data management.

Operations data provide information on the size of the operation in terms of annual production capacity, the brand and type of feed used, and the source and total volume of water used.

Since many fish culture operations utilize different culture units (i.e. circular tanks, raceways, troughs, ponds, etc.), an on-site decision was made by the investigator to conduct detailed sampling within a particular culture unit. Sampled Unit data provide information on the type and dimensions of the culture unit sampled, the total weight (or number) and size of fish in the unit, the method of feeding the fish (i.e. hand, demand feeder, automatic feeder) and the temperature and volumetric flow of water to the unit. As well, if water re-use was being utilized, the percentage of the total flow which was comprised of re-used water was also recorded.

Discussions with DOE and DFA representatives, and past experience in New Brunswick, revealed that several operations in the province utilize some form of effluent treatment. At those operations where treatment facilities were in operation at the time of the site visit, data were collected to permit an evaluation of the design parameters and operating efficiency of the treatment unit. Effluent Treatment data provide information on the treatment technology in place, the dimensions of the treatment unit, the hydraulic loading rate of the unit, and the design of inlet and outlet structures.

For most farms, sketches of the overall farm layout and process water flow paths were compiled to assist with data compilation and interpretation.

4.2.2 Response Variables

Response variables are divided into two distinct groups: water chemistry variables and solids settling variables.

At each fish culture operation, Water Chemistry Variables were collected in standard 1 litre and 1/4 litre sample bottles. The location and number of these samples varied somewhat with the nature of the culture facility; however, the influent source water and the final farm discharge were sampled at all operations. Samples were collected at the end of the "sampled production unit" and prior to and following effluent treatment, if the latter facilities were in operation.

The water quality parameters that were analyzed include total Kjeldahl nitrogen (TKN), total ammonia (NH_3), total phosphorus (TP), dissolved phosphorus (DP), and total suspended solids (TSS). Except for TSS, all water quality analyses were conducted by the N.B. DOE at their analytical laboratory in Fredericton. To ensure the confidentiality of individual fish culture operations included in the study, all samples were identified by a "Farm Number" only. Moreover, only the principal researchers have a record of the farm numbers and farm names.

To facilitate the segmentation of farms into discernible groups, and to enable the definition of principal effluent treatment design criteria, Solids Settling Data were also collected. A settling column measuring 220 cm high by 20.4 cm inside diameter was used to conduct on-site settling tests. Three sampling ports, located at distances of 120, 160, and 200 cm from the top of the column, were used to draw off samples for solids content analysis. Based upon past experience, two shallower ports (40 and 80 cm) were not used during this investigation.

Settling tests were conducted by filling the column to capacity with approximately 45 litres of water from the production/treatment unit. At most facilities, the water sample for the settling test was collected from the discharge channel and filtered through a cotton filter cloth. As suspended solids material collected on the filter cloth, the cloth began to blind, trapping finer particulate matter. Periodically, the cloth was gently rinsed into a collection container. This concentrated sample of farm effluent was then poured into the settling column for the sedimentation test. In some cases, it was necessary to re-suspend solids from within the production unit to gather samples having a sufficient concentration of solids for the analysis. Once in the column, the suspension was gently agitated by introducing compressed air through a sparger at the bottom of the column. Agitation serves to create a gentle rolling action in the column, thereby creating a uniformly mixed suspension from which to draw initial samples from each sampling port.

Following collection of the initial samples, the air supply was discontinued and the column contents were permitted to settle under quiescent

conditions. Samples were collected at timed intervals, which spanned a one-hour period. Past experience by the principal investigator has indicated that longer time periods (up to three hours) do not improve the quality of the data. All samples were vacuum filtered through type 11306 Sartorius Membrane Filters, having a pore size of 0.45 μm, to determine the total suspended solids concentration.

Settling data were not collected at all farms visited. Pond operations were excluded from this portion of the investigation due to the complexities introduced by suspended organic and inorganic matter naturally present in ponds. Additionally, settling tests were not conducted at farms where solids removal (via vacuuming, flushing, etc.) had not been conducted within the past seven days. Parjala (1984) suggests that solids be less than one week old to obtain reliable results. Generally, most operators had cleaned solids from their facilities within two to four days prior to the site visit.

4.2.3 Scope and Limitations

This field investigation was designed to enable the collection of data from a number of fish culture operations to provide a sufficiently broad data base to permit the segmentation of operations into discernible groups based upon production and management characteristics. Moreover, it was designed to maximize the co-operative efforts of all parties involved. To conduct a survey of this magnitude, over a geographic region the size of New Brunswick, necessitates that the time spent at individual sites be utilized efficiently.

Although composite sampling and/or multiple sampling programs offer certain advantages, the time required for such activities would greatly limit the total number of operations which could be visited, given the size of the geographic region surveyed in this study. Instead, grab samples were collected at each farm. Similarly, the utilization of filtered effluent samples and/or re-suspended solids for settling tests also permitted a larger number of sites to be visited during the sampling period. Nevertheless, additional insight may be provided through collection of solids in sediment traps for a 1 to 4 day period prior to conducting the sedimentation test. To dispel any argument regarding the solids sampling procedures applied in the field study, statistical comparison of settling data from re-suspended and filtered samples revealed no difference in settling behaviour. Similarly, no such differences were identified by CAS in studies conducted in Ontario.

In spite of these limitations, the study did achieve its objective of obtaining data from a number of fish culture operations; a data set which may, in fact, be unparalleled in the industry. Additionally, the nature of the data collected at all operations is essentially identical, thereby, incorporating uniformity into the investigation and subsequent interpretation of the results.

4.3 Data Analysis & Results

From September 10-16, 1989, a total of 11 land-based salmon smolt production operations were visited throughout New Brunswick. From this sample, full data sets, including settling data, water chemistry data, and production and management data, were obtained from 9 farms. Partial data sets were obtained from the remaining 2 farms. Of the latter, one is a pond culture operation and, therefore, settling data were not collected. The other facility was constructed in such a way that a representative effluent sample could not be collected for settling analysis. The following presentation of data analyses and results is largely based upon those 9 farms with complete data sets. Data from all farms visited are presented in Appendix II.

In total, 21 continuous variables (10 predictor variables; 6 solids settling variables; and 5 water chemistry variables) and 4 class, or non-continuous, variables (farm type; feed brand; feed type; and feeding method) were recorded. These variables are defined in Exhibit 4.1.

Prior to data analyses, all continuous data were transformed to natural logarithms to conform with assumptions of the various statistical methods. For each observation (z) the transformation equation is as follows:

$$\text{transformed value of } z = \ln((z+1) - \text{minimum z value})$$

By subtracting the minimum observed value from each variable, the data are adjusted for differences in measurement scales and units; adding 1 eliminates the potential for negative values associated with the logarithmic transformation of numbers less than 1.0.

Since a broad data set is available from a similar study conducted in Ontario during the summer of 1989, these data were incorporated into the present analysis to add insight into the importance of facility design and to facilitate the meaningful interpretation of results.

As one of the underlying goals of this investigation is to reveal practical cause-and-effect relationships between fish culture practices and deterioration of water quality, Pearson's (parametric) and Spearman's (non-parametric) correlation analyses were conducted on the entire data set to examine the nature of the relationships between variables. Key relationships between predictor variables and response variables were scrutinized. As suspected, however, very few statistically significant relationships were revealed, suggesting that considerable variability exists among intensive salmonid culture operations. As a result, data for the various farms were examined to determine whether different types of farming operations were evident.

Due to the physical layout and construction of intensive fish culture operations, it is relatively simple to separate farms on an *a priori* basis. That is, flow-through raceway facilities are distinct from oval raceways, and similarly from flow-through circular tanks, ponds, and intensive recirculation units. Consequently, data were re-organized into the following four groups prior to subsequent analyses.

Group 1 — Standard raceway operations in which water enters at one end, flows through the length of the unit, and is discharged at the opposite end.

Group 2 — Oval raceway operations resembling modified Burrows ponds in which two parallel raceways share a common dividing wall, which stops short of either end of the unit. Water circulates around the unit such that the flow on each side of the central wall is in opposite directions. High-volume low-head pumps are commonly used to maintain circulation within the tank. Overflow drains are usually located at one or both ends.

Group 3 — Ontario circular tank operations consisting of concrete, steel, or fiberglass tanks having a circular flow of water from the outer edge toward a central drain. Group 3 consists of Ontario Rainbow Trout production tanks exclusively.

Group 4 — New Brunswick circular tank operations consisting of concrete, or fiberglass tanks having a circular flow of water from the outer edge toward a central drain. Group 4 consists of New Brunswick Atlantic Salmon smolt production tanks exclusively.

Using this *a priori* approach, and the combined data set, 53 intensive salmonid culture farms were classified as follows:

Group	Class	(n)
1	Standard Raceways	21
2	Oval Raceways	11
3	Circular Tanks - Ont.	12
4	Circular Tanks - N.B.	9

Having classified the data into discernible groups, it was necessary to ascertain whether this classification strategy was statistically meaningful, based upon the observed variables. Using multivariate analysis of variance (MANOVA), the four groups were, in fact, found to be significantly different.

Multivariate Analysis of Variance
Test Criteria & F Approximation

Statistic	Value	F	Num DF	Den DF	Prob.
Wilks' Lambda	0.028885	3.1614	63	87.5	0.0001

From a univariate perspective using standard analysis of variance (ANOVA), significant differences between groups were identified across all 4 groups of variables (Exhibit 4.2). With respect to solids settling behaviour, New

Brunswick tank operations were found to have significantly different slopes for solids settling rate curves ($P<0.005$). Among the three Ontario farm types, no such differences were observed. From a production/management perspective, production area, standing crop, water flow, average fish size, total water flow, hydraulic retention time and temperature are responsible for distinguishing at least one of the four groups. Most notably, average fish size is significantly smaller ($P=0.0016$) and water temperature is significantly greater ($P=0.0514$) in New Brunswick operations. Similarly, in New Brunswick tanks the retention time of water in the facility is somewhat less than in Ontario tanks operations and oval raceways ($P=0.0013$); retention time is similar in standard raceway units ($P>0.05$). The four groups were found to differ with respect to all five water chemistry variables. Effluent concentrations of dissolved nutrients (i.e. TKN, NH3, TP, DP) are significantly greater ($P<0.0006$) in oval raceway operations than in the other three groups. However, New Brunswick tank operations were found to have significantly lower ($P=0.0239$) concentrations of effluent suspended solids, averaging two to four times less than that produced in Ontario trout operations (Exhibit 4.2).

To confirm this finding, and to visually present the magnitude of the difference between the four groups, a canonical discriminant analysis (CDA) was completed. CDA uses linear combinations of the observed variables in a multivariate approach to construct composite variables, which are comprised of components of all 21 variables. Canonical variables, or "axes," serve as the basis for classifying farms into one of the groups to confirm group membership and thereby identify unusual individual farms that fail to fit into the *a priori* grouping. One canonical axis is developed to maximally separate each pair of groups based upon the degree of variation inherent in the original data (for 4 groups, 3 canonical axes are generated). The analysis identifies variables which separate groups in combination as opposed to separating them on a "one variable at a time" basis (Campbell and Atchley 1981).

The CDA did indeed support the finding of the MANOVA, indicating that significant differences ($P<0.0001$) exist between the groups. The CDA results (Exhibit 4.3) illustrate that differences are significant along the first two canonical axes, which account for 91.8% of the variance between groups. The third axis, which accounts for the remaining 8.2% of total variance, was not significant ($P=0.3338$).

The four groups are plotted on the resultant canonical axes to visually display the results on X-Y co-ordinates (Exhibit 4.4). This graph illustrates that considerable overlap exists between standard raceways and Ontario circular tanks; the degree of overlap appears to be greater along axis 1 than on axis 2. Oval raceways are significantly removed from standard raceways and Ontario circular tanks along axis 1, and from New Brunswick circular tanks along both axes. The implication of this pattern is revealed by examining the canonical coefficients presented in Exhibit 4.5.

Standardized Canonical Coefficients are used to derive the actual data points which are plotted in Exhibit 4.4; they are the raw canonical coefficients, standardized to a standard deviation equal to unity. The total, within, and pooled canonical structures, however, reveal the correlations between the

original data and the canonical axes. More importantly, each structure presents a different aspect of the inter-relationship between and within groups.

The total canonical structure assumes that no groups exist. Generally, this summary reveals few strong correlations, however, significant correlations are indicative of important variables across all four groups. This analysis suggests that along canonical axis 1, the axis which maximally separates standard raceways and Ontario circular tanks from oval raceways and New Brunswick circular tanks, separation is principally due to differences in annual production, total production area, standing crop biomass, total water use, and all water chemistry variables except total suspended solids concentration. Along axis 2, which separates Ontario tank facilities from New Brunswick tank facilities, principal segmentation variables include settling curve slopes, total water use, water temperature, average fish size, hydraulic retention time, and all water chemistry variables except total dissolved phosphorus (Exhibit 4.5).

The between canonical structure compares the four groups collectively, using the mean or centroid of each group as the basis for comparison rather than the individual observations within each group (i.e. n=4 versus n=53). This approach identifies those variables which act to distinguish differences among groups and is similar to MANOVA in that multi-variable interaction is used. The high correlation coefficients for the between canonical structure along both axes in Exhibit 4.5 suggest that nearly all of the measured variables contribute to group separation. In fact, density is the only variable which is not highly correlated on either canonical axis, suggesting that the between group differences are not attributed to this variable.

Lastly, the within canonical structure questions the degree of variability for each variable within each group and across groups. That is, it considers whether the role of one variable in one group is similar to the relationship of that same variable in other groups. High correlations suggest that a relationship exists within groups and across groups. The data in Exhibit 4.5 reveal strong correlations for total water use and dissolved phosphorus along axis 1, and for the slope of the cumulative solids settling curve, average fish size, hydraulic retention time, ammonia, total Kjeldahl nitrogen, and total suspended solids along axis 2. For these variables, the correlation that exists within each group is similar to the correlation that exists between groups.

Having identified that the fundamental design of fish production facilities is indeed a basis for separating the groups, individual group data were then examined to further quantify and qualify the impact of fish production practices and system design on the quality and treatment of discharged effluent. Correlation analysis is an effective tool for revealing relationships between the observed variables. Both Pearson's (parametric) and Spearman's (non-parametric) correlation analyses were used to resolve patterns in the transformed data sets for Groups 1 through 4, individually.

Differences between Pearson's and Spearman's analyses revealed that several of the relationships are not linear. Consequently, Spearman's correlation analysis was considered to be more appropriate. This technique compares data on a rank order basis and provides a more conservative interpretation of results. Tables of Spearman correlation coefficients and the corresponding statistical

probabilities are attached in Appendix III. Exhibit 4.6 presents the correlation coefficients and statistical probabilities for those relationships which are particulary meaningful to the study.

A number of the predictor variables (i.e. production area, depth, flow, density, etc.) are highly correlated (Appendix III); this is to be expected since many of these variables are inter-related by design. For example, the carrying capacity of an operation (standing crop) is generally related to the available supply of water. Similarly, the solids settling data and water chemistry data tend to be highly correlated with their own kinds. More importantly, however, we must understand the relationships between the predictor variables and both solids settling variables and water chemistry variables to properly assess the impact of aquaculture operations on water quality, and thereby facilitate the design of effective effluent treatment units.

With respect to the solids settling data, statistically significant and meaningful correlations were only found in New Brunswick tank operations, where the intensity of production and the mean fish density were found to be negatively correlated with the intercept of the cumulative solids settling curve (Exhibit 4.6). This implies that, as intensity and/or density increase, the intercept of the settling curve decreases, implying that effluent treatment is facilitated when production practice is intensified. This finding is contrary to expectation since it is logical that increased intensities result in the reduction of suspended particulate matter into smaller and smaller fractions. In fact, similar correlations were not observed in any of the other groups. Among the remaining groups and variables, those relationships that are significant have little meaning since the correlated variables have little relevance from a design or management perspective (Exhibit 4.6; Appendix III).

Several meaningful relationships have also been identified between production and water chemistry variables. In all production systems, increases in intensity are significantly correlated ($P<0.10$) with an increase in the effluent concentration of NH3, TKN, TP, and/or DP (Exhibit 4.6). The depth of production facilities and the weight of the standing crop of fish are correlated with the concentration of TKN in effluent waters in standard raceways and Ontario tank operations. Increases in standing crop and density are highly correlated ($P<0.05$) with increases in effluent TP in Ontario tanks as well. Weak positive correlations ($P<0.10$) exist between average fish size and TKN and NO_2 in standard raceways and Ontario tanks. There is also evidence suggesting a positive correlation between average fish size and TP concentration in Ontario tanks.

In spite of some similarities, New Brunswick tank operations display a somewhat different set of correlated variables. Most meaningfully, production area and total water flow are correlated with the effluent concentrations of total and dissolved phosphorus (Exhibit 4.6). As production area and total water flow increase, the effluent concentration of total and dissolved phosphorus decreases. Given a constant biomass of fish, both of these relationships suggest lower effluent concentrations of phosphorus due to dilution; the mass load of phosphorus, however, is undoubtedly unchanged.

Once again, several similarities between standard raceways and Ontario circular tanks, and dissimilarities between these two groups and oval raceways,

are revealed. New Brunswick tank operations have correlated variables most similarly resembling oval raceway operations, although this similarity is not strong (Exhibit 4.6). Depth and average fish size have an impact on water quality in both standard raceways and Ontario tanks, yet they have no effect in oval raceway and New Brunswick tank operations. Additionally, total flow has no impact in standard raceways and Ontario tanks, but it is correlated with effluent water chemistry in oval raceways and New Brunswick tanks. The production variables for which no meaningful correlations were identified across all three groups include hydraulic retention time, and annual production. Conversely, production intensity is most meaningful across all groups.

The objectives of this investigation clearly indicate a need for the establishment of design criteria to facilitate solids removal from fish culture process water. While the data analysis and results thus far have provided valuable insight into those factors which lead to deterioration of water quality, they have not, however, produced a substantial amount of information pertaining to solids settling characteristics. As discussed in Section 3.1, settling data can be plotted to yield a cumulative distribution curve, which is utilized as a primary tool in the design of sedimentation basins. Such data were collected at 9 New Brunswick farms and 44 Ontario farms during field surveys. The data from the 53 operations comprising Groups 1, 2, 3, and 4 have been analyzed using regression analysis, and compared using analysis of covariance (ANCOVA).

ANCOVA was first used within each group to determine the degree of within-group variation, and the possible sources of such variation. Within all four groups of farms, clusters of farms were found to have regression equations which were different from other clusters within the group. The number of within-group clusters, and the degree of overlap between successive clusters, however, indicates that these within-group differences are subtle, and are relatively unimportant in comparison with between group differences. Among the New Brunswick tank operations, however, one farm in particular (Farm 91) was found to differ significantly ($F=11.3$; $P<0.01$) from the remainder of the group. The most notable difference in the defining characteristics about this farm is the use of Connors Bros. Ltd.[1] moist feed. Among other farms, feed brand, feed type, and feeding method were explored as possible sources of between group differences, however, no pattern was found.

Before undertaking subsequent ANCOVA analyses, ln-transformed data from all farms were pooled into each of the four respective farm groups: standard raceways, oval raceways, Ontario circular tanks, and New Brunswick circular tanks. In the New Brunswick group, the farm using moist feed was eliminated from the pooled data based upon the finding stated above. For each group, a significant regression equation was obtained ($P<0.001$). The un-transformed regression lines (settling curves) for each group (and for N.B. Farm 91, which utilizes moist feed) are plotted in Exhibit 4.7.

Across all groups, the data obtained at each farm from the three sampling ports on the settling column continuously fall on a single regression line, with an overall average coefficient of determination (r^2) greater than 60%. This

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[1] Connors Bros. Ltd., Feed Division, Beaver Harbour, N.B.

confirms that settling is indeed discrete in intensive salmonid fish culture. The regression equations for the pooled data set for each group and Farm 91 are presented below. A detailed regression analysis of the N.B. Tank data is presented in Appendix V.

Group	Equation	F	P	n	r^2
Std. Raceways	ln Cr = 0.09889 + 0.80730 ln Vo	474.1	P<0.001	270	0.638
Oval Raceways	ln Cr = 0.31979 + 0.72947 ln Vo	282.2	P<0.001	159	0.640
Ontario Tanks	ln Cr = 0.06397 + 0.72781 ln Vo	277.1	P<0.001	151	0.648
N.B. Tanks	ln Cr = 0.47770 + 0.39804 ln Vo	320.7	P<0.001	101	0.764
N.B. Farm 91	ln Cr = 0.41223 + 0.88010 ln Vo	141.0	P<0.001	14	0.922

ANCOVA was used to identify similarities and differences between these equations. Prior to conducting the ANCOVA, an F_{max} test revealed heterogeneity of variance, implying that one/some of the regressions are more variable than the others. This heterogeneity can be quantified by comparing the r^2 values for the equations; the variance lies in the higher value for N.B. tank operations and Farm 91. Since the total degrees of freedom are greater than unity, and since all of the regressions are highly significant, the consequences of this moderate heterogeneity of variance should not influence the analysis and interpretation of data to any meaningful extent.

The analysis indicates that the slopes of the four lines are significantly different ($F=14.3$; $P<0.05$). Furthermore, this difference is attributed to the greater slope of the settling curve for New Brunswick tank operations. In fact, the slopes of the curves for standard raceways, oval raceways, and Ontario tanks are not significantly different ($F=1.35$; $P>0.05$); however, the intercepts of these lines are different ($F=5.5180$; $P<0.01$). Interestingly, it is the intercept of the cumulative distribution curve for oval raceways which is significantly different from the intercepts of standard raceways and Ontario circular tanks. The latter are not significantly different, thereby further substantiating the similarities between these two groups. From the plots in Exhibit 4.7, it is evident that solids removal is facilitated in Ontario operations versus New Brunswick operations, as indicated by the upward shift in the cumulative distribution settling curve for New Brunswick farms. This implies that, to achieve the same level of efficiency, New Brunswick salmon smolt operations will require a settling basins of larger area than Ontario trout operations.

At Ontario operations, the class variable "feed brand" was assessed as a possible contributor to effluent water quality. Effluent water chemistry data were re-grouped by the brand of feed used at the culture facility. The groups

consisted of (1) users of Martins Feed[2]; (2) users of Zeigler's Feed[3]; and (3) users of a combination of these two brands. No other feed brands were cited in the survey.

MANOVA was used to assess the impact of feed brand on effluent water quality. No significant difference was found between groups.

Multivariate Analysis of Variance
Test Criteria & F Approximation

Statistic	Value	F	Num DF	Den DF	Prob.
Wilks' Lambda	0.82044	0.60926	14	82	0.8500

Furthermore, univariate F-tests (ANOVA) revealed no significant difference (P>0.406) in effluent concentrations of ammonia, TKN, nitrite, nitrate, total phosphorus, dissolved phosphorus, or total suspended solids between farms using either feed brand.

A similar analysis was not conducted for New Brunswick operations since nearly all operations utilize a combination of Zeigler Bros. and Corey feeds. The only exceptions to this include the partial use of Moore-Clarke[4] feed by one farm and the use of Connors Bros. moist feed by another. Moreover, the limited data set (n=9) is not conducive to statistical analysis.

Similarly , MANOVA and ANOVA were used to examine the effect of feed brand on solids settling characteristics for Ontario farms and, again, no significant differences were observed using either univariate or multivariate techniques (P>0.232).

Multivariate Analysis of Variance
Test Criteria & F Approximation

Statistic	Value	F	Num DF	Den DF	Prob.
Wilks' Lambda	0.86624	0.79783	6	31	0.5790

Once again, the data set did not permit a similar analysis for New Brunswick operations. However, the results of the ANCOVA analysis may indicate that the use of a moist diet facilitates quicker solids settling behaviour, as reflected by the downward shift in the cumulative distribution settling curve for Farm 91 in comparison to the other New Brunswick operations (Exhibit 4.7).

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[2] Martin Feed Mills Ltd., Elmira, Ontario.

[3] Zeigler Bros., Inc., Gardners, PA.

[4] Moore-Clark Co. (Canada) Inc., Vancouver, B.C.

4.4 Chapter Summary and Principal Findings

4.4.1 The four *a priori* groups of farms (i.e. standard raceways, oval raceways, Ontario tanks, and N.B. tanks) display significant differences with respect to design, operating, and effluent water quality perspectives. Most notably, New Brunswick farms produce much smaller fish (28 gram parr versus 250 gram table size trout), have slightly warmer water, and significantly lower effluent concentrations of total suspended solids. This latter factor can be largely attributed to higher flow rates, in spite of similar standing crops, densities, and production intensities.

4.4.2 Strong correlations exist between production parameters and effluent water quality. Most notably, increased intensity (i.e. carrying capacity) results in increased concentrations of nutrient pollutants (NH_3, TKN, TP and/or DP) in all four groups of production facilities. In New Brunswick tanks, total production area and total hydraulic flow are inversely proportional to the effluent concentrations of TP and DP. This suggests that dilution minimizes the effluent concentration of these pollutants, however, it does not reduce the mass load. The poorest quality effluent was observed at Ontario oval raceway production facilities.

4.4.3 As expected, the retention time of water in the production system and the annual production level of a farm are not related to any aspect of effluent water quality. This suggests that all farms, big and small, have the potential to pollute receiving bodies of water.

4.4.4 Solids settling behaviour was observed to differ moderately within individual groups, however, the between-group differences were highly significant and inherently more meaningful. New Brunswick tank operations display significantly slower solids settling behaviour than do Ontario trout farming operations. This may be due, in part, to the smaller average size of fish raised in the New Brunswick operations. Further evidence suggests that moist feed may promote faster solids settling performance in New Brunswick smolt production. Among the Ontario trout farms, oval raceway operations were found to have significantly slower settling rates than either standard raceways or circular tanks. The latter are not significantly different.

Exhibit 4.1:
Definition and units of measure for the 21 continuous and 4 class variables observed and recorded at the time of the site visit. The abbreviated name used in the results section is also presented.

Variable Name	Units	Abbr.	Definition
<u>Predictor Variables - Continuous</u>			
Intensity	(kg/Lps)	INTEN	The approx. biomass of fish within the observed production unit per unit water flow.
Annual Production	(kg)	PROD	The approx. total weight of fish produced at the facility each year.
Production Area	(m^2)	AREA	The surface area of the sampled production unit.
Production Depth	(m)	DEPTH	Average depth of the sampled production unit.
Standing Crop	(kg)	CROP	The approx. weight of fish within the sampled production unit.
Density	(kg/m^3)	DENS	The approx. weight of fish per unit volume in sampled production unit.
Water Flow	(Lps)	FLOW	Total water flow through sampled production unit.
Temperature	(°C)	TEMP	Water temperature.
Average Fish Size	(g)	SIZE	The average weight of an individual fish within the sampled unit.
Hydraulic Retention Time	(min)	HRT	The theoretical retention time of water within the production unit based on volumetric flow of source water.

Exhibit 4.1: (cont'd)
Definition and units of measure for the 21 continuous and 4 class variables observed and recorded at the time of the site visit. The abbreviated name used in the results section is also presented.

Variable Name	Units	Abbr.	Definition
<u>Predictor Variables - Class</u>			
Farm Type	--	GROUP	Standard raceways, oval raceways, circular tanks (Ont. / N.B.).
Feed Brand	--	FEED	Martins, Zeigler's, Corey, Moore-Clarke, Connors, combination, other.
Feed Type	--	TYPE	Sinking, floating, combination.
Feeding Method	--	METH	Hand, demand, automatic, other.
<u>Response Variables - Settling Data</u>			
Slope - Port 1	--	m1	Slope of regression line for [TSS] versus time for 120 cm port samples.
Slope - Port 2	--	m2	Slope of regression line for [TSS] versus time for 160 cm port samples.
Slope - Port 3	--	m3	Slope of regression line for [TSS] versus time for 200 cm port samples.
Slope - CDC	--	mCDC	Slope of regression line for the cumulative distribution curve for sedimentation data.
Intercept - CDC	--	INTPT	Intercept of regression line for the cumulative distribution curve for sedimentation data.
Coefficient of Determination - CDC	--	r^2	Coefficient of determination of the regression equation for the cumulative distribution curve for sedimentation data.

Exhibit 4.1: (cont'd)
Definition and units of measure for the 21 continuous and 4 class variables observed and recorded at the time of the site visit. The abbreviated name used in the results section is also presented.

Variable Name	Units	Abbr.	Definition
Response Variables - Water Chemistry			
Total Kjeldahl Nitrogen	(mg/L)	TKN	KSO_4 / H_2SO_4 Digestion - Colorimetric @ 630 nm
Total Ammonia	(mg/L)	NH_3	Undigested - Colorimetric @ 630 nm
Total Phosphorus	(mg/L)	TP	KSO_4 / H_2SO_4 Digestion - Colorimetric @ 880 nm
Dissolved Phosph.	(mg/L)	DP	Undigested - Colorimetric @ 880 nm
Total Suspended Solids	(mg/L)	TSS	Filtration through 0.45 μm membrane filter paper.

Exhibit 4.2:
ANOVA table of means for standard raceway, oval raceway, Ontario circular tank, and New Brunswick circular tank salmonid fish culture facilities. Values with similar superscripts are not significantly different (P>0.05). Water quality data is reported net of source water.

Variable	Group Means				ANOVA Results	
	Raceways	Ovals	ON Tanks	NB Tanks	F	P
Slope - Port 1	-0.567^{b}	-0.493^{ab}	-0.573^{b}	-0.301^{a}	3.52	0.0216
Slope - Port 2	-0.597^{b}	-0.503^{b}	-0.507^{b}	-0.259^{a}	6.14	0.0012
Slope - Port 3	-0.600^{b}	-0.464^{b}	-0.591^{b}	-0.230^{a}	4.96	0.0044
Slope - CDC	0.672^{b}	0.678^{b}	0.775^{b}	0.436^{a}	3.73	0.0171
Int. - CDC	0.037	0.184	0.031	0.371	1.17	0.3310
r2 - CDC	0.818	0.890	0.768	0.781	1.23	0.3098
Ann. Prod'n (kg)	41451	35263	13480	27619	1.54	0.2160
Prod'n Area (m2)	186.3^{a}	368.7^{b}	63.3^{a}	590.2^{b}	5.89	0.0016
Prod'n Depth (m)	0.89	1.00	0.79	0.91	1.09	0.3612
Standing Crop (kg)	10417^{ab}	8216^{ab}	996^{a}	6973^{b}	6.72	0.0007
Density (kg/m3)	28.0	20.6	16.8	17.7	1.10	0.3585
Avg Fish Size (g)	341.0^{b}	206.2^{b}	206.5^{b}	27.5^{a}	5.92	0.0016
Water Flow (Lps)	66.28^{b}	87.06^{a}	5.11^{c}	130.4^{a}	15.20	0.0001
Intensity (kg/Lps)	198.7	125.3	246.8	76.5	0.93	0.4320
Hydr Ret'n Time (min)	139.1^{b}	337.7^{a}	260.4^{a}	68.2^{b}	6.11	0.0013
Temperature (C)	11.1^{a}	10.6^{a}	10.6^{a}	14.4^{b}	2.77	0.0514
Tot Kjeldahl N (mg/L)	0.871^{a}	3.192^{b}	1.495^{a}	0.559^{a}	10.08	0.0001
Ammonia (mg/L)	0.362^{a}	1.836^{b}	0.757^{a}	0.241^{a}	8.62	0.0001
Tot Phosphorus (mg/L)	0.077^{a}	0.354^{b}	0.158^{a}	0.109^{a}	6.83	0.0006
Dis Phosphorus (mg/L)	0.027^{a}	0.121^{b}	0.032^{a}	0.052^{a}	11.72	0.0001
Susp. Solids (mg/L)	7.007^{b}	7.076^{b}	11.148^{b}	2.790^{a}	3.44	0.0239

Exhibit 4.3:
Canonical discriminant analysis - statistical results for segmentation of five *a priori* groups of salmonid fish culture facilities.

CANONICAL AXIS	CANONICAL CORRELATION	EIGENVALUE	PROPORTION	CUMULATIVE PROPORTION
1	0.929	6.311	0.719	0.719
2	0.798	1.750	0.199	0.918
3	0.648	0.722	0.082	1.000

CANONICAL AXIS	LIKELIHOOD RATIO	APPROXIMATE F VALUE	NUM D.F.	DEN D.F.	PROBABILITY
1	0.029	3.161	63	87.4	0.0001*
2	0.211	1.764	40	60.0	0.0227*
3	0.581	1.178	19	31.0	0.3338

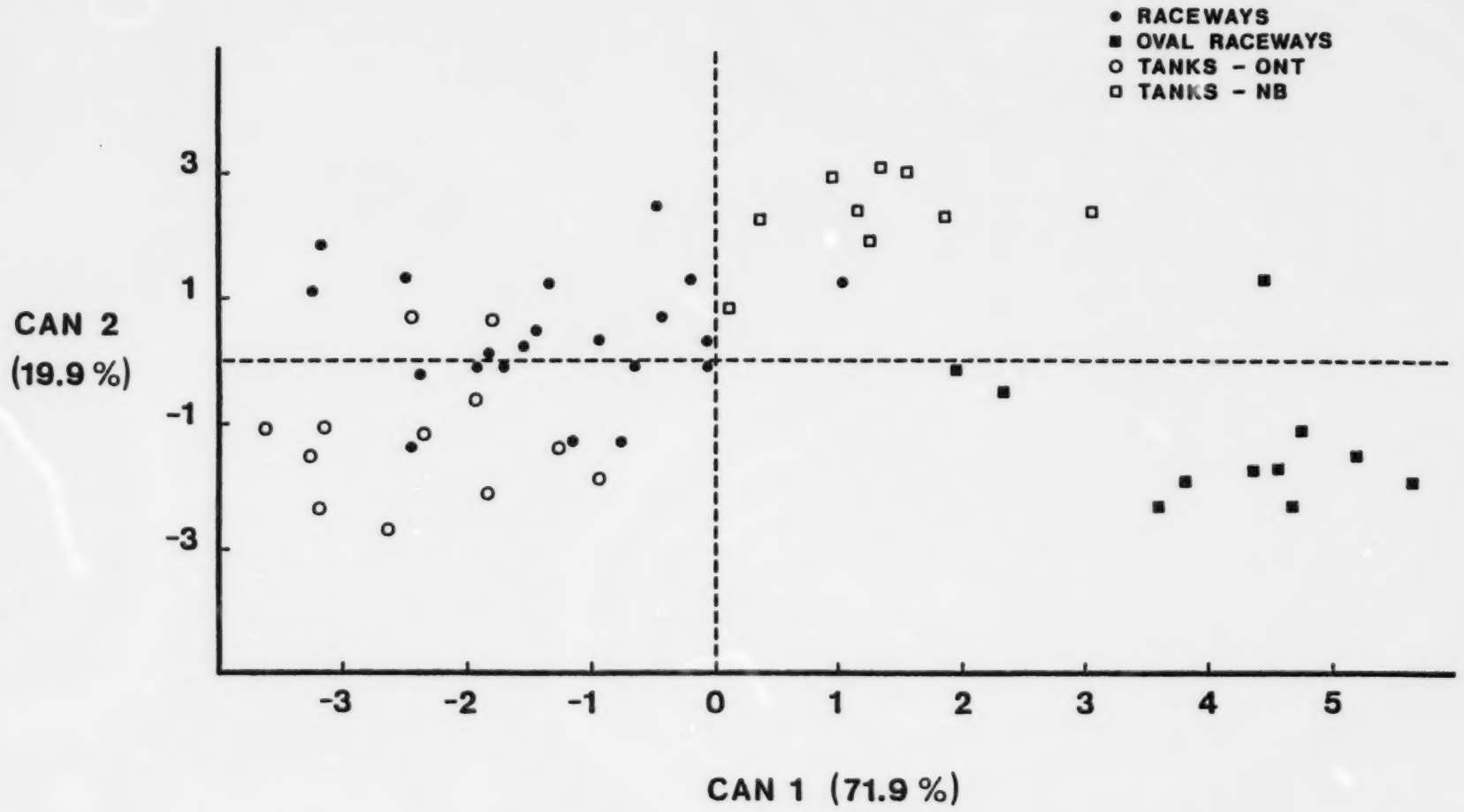

Exhibit 4.4:
Canonical discriminant analysis: Plot of canonical axes 1 and 2, identifying group separation among four classes of commercial salmonid aquaculture operations. Both axes are statistically significant ($P<0.025$). Bracketed value indicates percentage of observed variance accounted for in axis.

CANADIAN AQUACULTURE SYSTEMS

Exhibit 4.5:
Canonical Discriminant Analysis: Canonical coefficients and total, within and between canonical structures for Groups 1 - 5. Coefficients >0.30 are generally meaningful.

Variable	Standard'd Coef.		Tot. Can. Struct.		Between Struct.		Pooled Within	
	CAN1	CAN2	CAN1	CAN2	CAN1	CAN2	CAN1	CAN2
m1	0.174	-0.204	0.256	0.372	0.565	0.704	0.104	0.247
m2	-0.262	-0.208	0.279	0.476	0.496	0.727	0.121	0.337
m3	-0.283	0.053	0.305	0.405	0.586	0.669	0.129	0.279
SLOPE CDC	-0.529	-0.798	-0.174	-0.492	-0.375	-0.910	-0.071	-0.329
INTERCEPT CDC	0.183	0.255	0.158	0.202	0.568	0.623	0.060	0.126
r^2 CDC	-0.133	0.096	0.215	-0.107	0.757	-0.323	0.083	-0.067
INTENSITY	-0.785	-0.249	-0.178	-0.185	-0.713	-0.636	-0.068	-0.115
ANNUAL PROD'N	-0.049	-0.199	0.311	-0.057	0.984	-0.155	0.120	-0.036
PROD'N AREA	-2.456	-0.623	0.543	0.096	0.980	0.148	0.234	0.067
PROD'N DEPTH	-1.279	-0.043	0.269	0.011	0.999	0.035	0.103	0.007
STANDING CROP	0.466	1.477	0.545	0.191	0.938	0.283	0.239	0.137
DENSITY	0.418	-0.173	0.067	0.036	0.246	0.115	0.025	0.023
WATER FLOW	4.051	-0.440	0.686	0.299	0.934	0.351	0.347	0.247
TEMPERATURE	0.028	0.630	0.046	0.443	0.111	0.928	0.018	0.289
FISH SIZE	0.079	-0.268	-0.008	-0.497	-0.015	-0.768	-0.004	-0.350
HYDR. RET'N TIME	2.084	-0.337	0.185	-0.583	0.329	-0.891	0.080	-0.412
AMMONIA	-0.277	-0.264	0.393	-0.567	0.621	-0.769	0.180	-0.423
TOTAL KJELDAHL N	0.086	-0.585	0.405	-0.613	0.608	-0.792	0.190	-0.470
TOTAL PHOSPHORUS	0.624	0.335	0.457	-0.398	0.781	-0.585	0.201	-0.286
DISS. PHOSPHORUS	0.759	-0.071	0.656	-0.253	0.944	-0.313	0.318	-0.200
TOTAL SUSP. SOLIDS	-0.438	-0.366	-0.101	-0.507	-0.225	-0.970	-0.041	-0.336

Exhibit 4.6:
Spearman correlation coefficients and statistical probabilities of finding such correlations by chance between predictor and response variables among the four groups of intensive salmonid fish culture operations.

Variables	Corr. Coef.	P	Variables	Corr. Coef.	P
STANDARD RACEWAYS					
INTEN - TKN	0.462	0.035	INTEN - TP	0.372	0.097
INTEN - DP	0.584	0.005	DEPTH - TKN	0.396	0.076
CROP - TKN	0.371	0.097	SIZE - TKN	0.414	0.062
SIZE - NO2	0.430	0.052			
OVAL RACEWAYS					
INTEN - TKN	0.627	0.039	INTEN - TP	0.718	0.013
INTEN - DP	0.773	0.005	CROP - NH3	0.582	0.060
CROP - TKN	0.600	0.051	CROP - TP	0.564	0.071
CROP - DP	0.791	0.004	DENS - NH3	0.545	0.083
FLOW - NO3	0.734	0.010			
CIRCULAR TANKS - ONTARIO					
INTEN - NH3	0.804	0.002	INTEN - TKN	0.664	0.019
INTEN - TP	0.776	0.003	DEPTH - TKN	0.790	0.002
DEPTH - TP	0.580	0.048	DEPTH - TSS	0.524	0.080
CROP- TKN	0.545	0.067	CROP - TP	0.727	0.007
DENS - TP	0.552	0.063	SIZE - TKN	0.510	0.090
SIZE - NO2	0.497	0.099	SIZE - TP	-0.508	0.092
SIZE - DP	0.601	0.039			
CIRCULAR TANKS - NEW BRUNSWICK					
INTEN - INTPT	-0.817	0.007	INTEN - NH3	0.817	0.007
DENS - INTPT	-0.683	0.042	DENS - NH3	0.917	0.005
AREA - TP	-0.812	0.008	AREA - DP	-0.758	0.018
FLOW - TP	-0.812	0.008	FLOW - DP	-0.715	0.030
TEMP - MD	0.600	0.088	TEMP - INTPT	0.600	0.088
TEMP - TP	-0.820	0.077	TEMP - DP	-0.655	0.055
TEMP - TSS	-0.783	0.013			

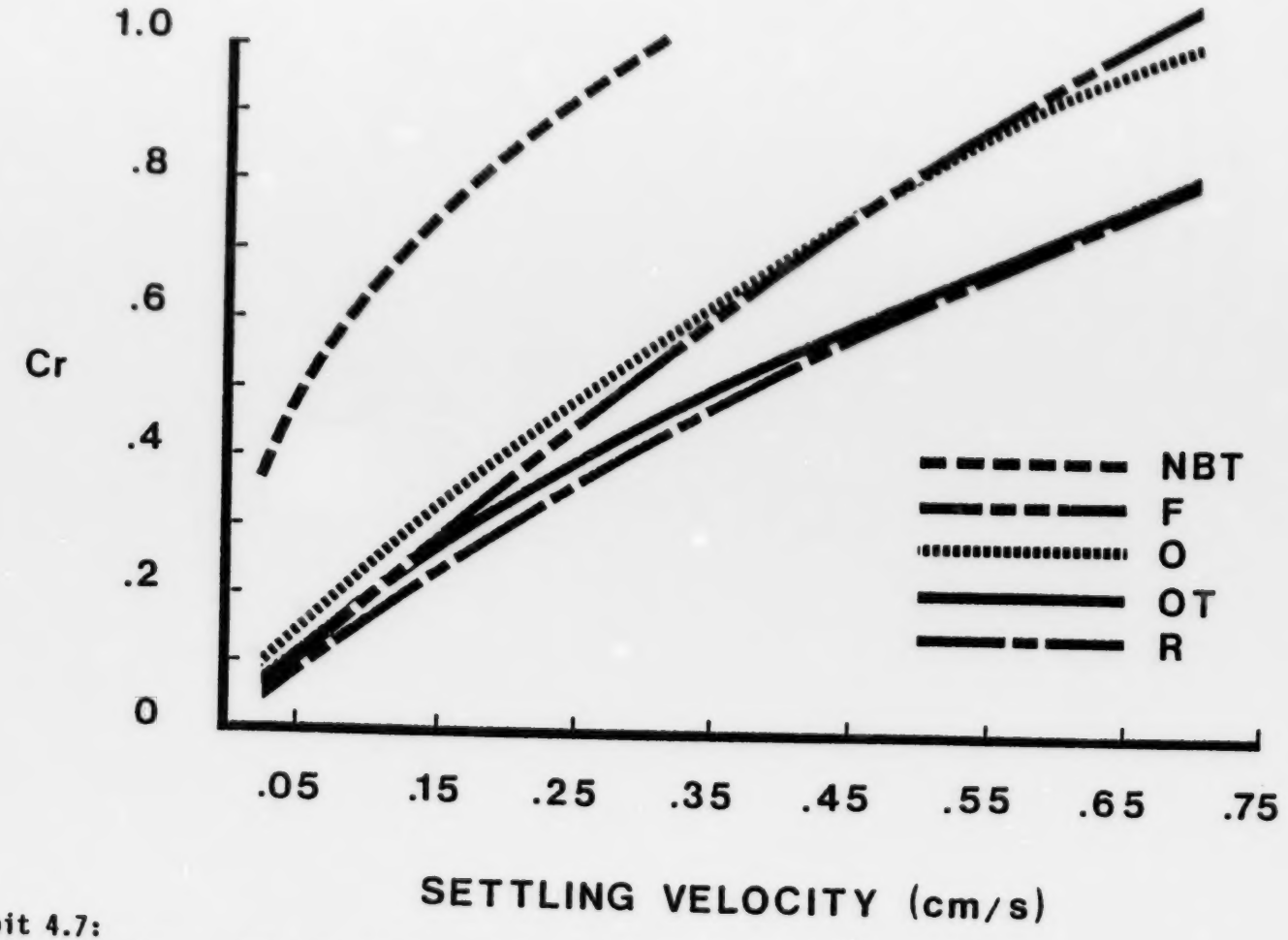

Exhibit 4.7:
Settling velocity profile for suspended solids from intensive salmonid production facilities. R = standard raceways; O = oval raceways; OT = Ontario circular tanks; NBT = New Brunswick circular tanks; F = Farm 91.

5.0 STATUS OF AQUACULTURE EFFLUENT TREATMENT

The farms included in Groups 1 through 4 comprise the majority of smolt production capacity in New Brunswick and a substantial proportion of the commercial trout producers in Ontario. In New Brunswick, nearly all operations utilize effluent treatment facilities. Settling ponds are the main treatment technique; however, one operation utilizes triangle filters and another has no treatment facilities at all. Of the Ontario operations, nearly half of the farms visited utilize some means of effluent treatment prior to discharging process water from their facilities. Sedimentation technologies are applied exclusively at the Ontario farms visited; the use of technologically advanced filtration equipment for effluent treatment has not been witnessed on a commercial scale in the province.

5.1 Current Application of Settling Facilities in Aquaculture

Four principle gravitational solids removal strategies are used in commercial aquaculture today: (1) in-raceway settling basins; (2) external, rectangular basins; (3) external ponds; and (4) external circular basins.

In-raceway settling consists of allocating a portion of the raceway unit for settling, usually at the downstream end. Screens are typically used to keep fish out of the settling area, however, it is not uncommon for a few fish to be present in the quiescent zone. In some instances, overflow or underflow weirs are used to introduce water to the settling zone. In virtually all cases, flow is introduced across the entire width of the raceway. Few operators utilize full-width discharge weirs, however, as overflow discharge standpipes tend to be more common.

Due to the physical layout of some fish culture facilities, the major stream of process water is not treated within the culture unit but rather it is subsequently treated in a separate sedimentation basin. Such units must be large enough to accommodate the entire water flow of the farm. In these instances, rectangular concrete basins, earthen ponds, and/or circular basins are used.

External rectangular basins are often much like raceways, however, they are frequently wider and shorter. Flow is usually introduced through a modified pipe inlet, not dissimilar from those inlet structures depicted in Exhibit 3.5. The use of submerged, wide-top weirs is limited. Outlet structures vary between full-width overflow weirs and vertical standpipes.

Earthen pond settling basins were the accepted fish farm effluent treatment process of the past. While most ponds have been designed with a substantial surface area for settling, poor inlet and outlet design, excessive depth, and the inability to clean solids from the bottom render them inefficient and or ineffective in many applications. These design flaws generally stem from out-dated criteria mandating a specific retention capacity within the pond. Moreover, point source inlet and outlet structures tend to be the norm, thereby exacerbating the inherent inefficiency of ponds. Furthermore, Westers (1989) indicates that, when solids are allowed to accumulate over long periods of time, settling ponds may function as nutrient sinks, accumulating solid nutrients only

to later release them in dissolved form following decomposition and solubilization.

In recent years, the use of circular settling basins has evolved in aquaculture. These basins are typically constructed of galvanized steel silo walls, which are laid into a concrete pad. A single pipe inlet conventionally rises from below ground at the centre of the tank. A distribution baffle, constructed of a perforated steel or plastic barrel, is usually placed over the inlet pipe, extending from the floor to the surface of the basin. This baffle serves to reduce turbulence and distribute the flow radially across the tank. The outlet from the basin most commonly consists of perforated drainage tile which is moored at the basin surface around the perimeter of the tank. In spite of the use of this effective design, some operators utilize circular basins with a peripheral inlet and a central drain. In the latter cases, internal baffles are often used to control the flow of water within the basin. This inward flow approach is comparatively inefficient.

5.2 Effectiveness of Existing Treatment Operations

During the field survey component of this investigation, specific design and operations data were collected from existing effluent treatment facilities at fish culture operations. Only those facilities from which it was possible to obtain water samples from the treatment influent and effluent flows, and where the dimensions and total water flow through the treatment unit could be quantified, were included in this portion of the study. In all, 33 treatment units were sampled; 26 units were sampled at 24 Ontario farms, along with 7 units at New Brunswick smolt facilities. The 17 observed variables are defined in Exhibit 5.1.

A priori segmentation was used to classify the different treatment methods into the four principal groups (described in Section 5.1) prior to statistical analysis. MANOVA was used to identify differences between the groups.

Multivariate Analysis of Variance
Test Criteria & F Approximation

Statistic	Value	F	Nm DF	Den DF	Prob.
Wilks' Lambda	0.00850	4.5803	42	48.2	0.000

Using univariate ANOVA, coupled with Student-Newman-Keuls multiple range tests, between-group differences were found to be associated with settling area, hydraulic loading, overflow rate, inlet area, outlet weir rate, settling basin depth, and average fish size. However, no differences in removal efficiency of four water chemistry variables (TSS, TKN, TP, DP) were observed between the different types of treatment facilities (Exhibit 5.2).

The data indicate that the removal efficiency of TSS from aquaculture effluents is poor, averaging only 29.5% in in-raceway settling facilities, 31.7% in external, rectangular basins, 15.5% in external circular basins, and 30.6% in ponds. Similarly, removal of total phosphorus is also poor, averaging only 0.8%

in in-raceway treatment units, 38.3% in external rectangular basins, and 11.7% in ponds. External circular basins displayed an average net increase in total phosphorus. For dissolved phosphorus, effluent concentrations were greater than influent concentrations in all treatment designs (Exhibit 5.2), confirming that a portion of particulate phosphorus quickly becomes solubilized within the system. Data for all treatment units are presented in Appendix IV.

Examination of the design and operating parameters for these effluent treatment facilities provides several explanations for the overall poor level of performance. In spite of various recommendations which suggest that design overflow rates be in the range of 40 to 80 $m^3/m^2/d$ for aquaculture clarifiers (note that this is not necessarily a recommendation of this report; see Section 7), average design overflow rates were found to surpass this range in 17 of 33 cases. Values ranging from 85.9 $m^3/m^2/d$ in external rectangular basins to 344.3 $m^3/m^2/d$ in external circular basins were observed (Exhibit 5.2). Only pond treatment operations have an average overflow rate within recommended guidelines. In fact, the greatest overflow rate in observed pond treatment facilities is 41.3 $m^3/m^2/d$. Notice, too, that external rectangular basins and ponds have higher average removal efficiencies for TSS and TP than do in-raceway and external circular basins; the difference, however, is not statistically significant. This difference is likely a reflection of overflow rate, although certainly not exclusively. Outlet weir rates which exceed design recommendations by approximately 2 to 6 fold were observed at 26 of the 33 treatment facilities (Exhibit 5.2).

Since all four groups were found to have similar treatment efficiency, design and operations variables were correlated with water chemistry variables in search of meaningful relationships within the total data set. Correlation coefficients and statistical probabilities are presented in Exhibit 5.3. The available surface area for sedimentation (area of the settling basin) and overflow rate hold the most meaningful correlations with respect to treatment efficiency. Overflow rate (Vo) is positively correlated with TSS removal ($P=0.014$), indicating that the higher the overflow rate, the lower the efficiency of suspended solids removal. Recall from Exhibit 5.1 that the water chemistry data assessed in this analysis consist of ratios of treatment effluent to treatment influent -- the lower the number, the lower the effluent concentration relative to the influent concentration. Similarly, basin surface area is significantly correlated with TSS removal ($P=.090$). The negative correlation coefficient indicates that an increase in surface area is concomitant with enhanced removal of TSS. Both of these relationships are logical since solids removal is directly proportional to area, and inversely proportional to overflow rate.

The cross sectional area of the inlet zone was found to be positively correlated with DP removal ($P=.013$), implying that removal of DP decreases as cross sectional area of the inlet zone increases; this cannot be explained. Conversely, however, removal of dissolved phosphorus is enhanced ($P=.046$) when hydraulic retention time is increased (Exhibit 5.3), as is the removal of TSS and TKN. Since retention time is itself immaterial, these relationships likely reflect the overflow rate and surface area relationships discussed above. That is, given a constant hydraulic load, as surface area increases or overflow rate decreases, retention time generally increases as well. The improved performance,

however, is more realistically a factor of these latter two variables for the following reason. Retention time is the quotient of the volumetric flow rate divided by basin volume and, therefore, an increase in volume leads to an increased retention time. Increased volume, however, is generally attributed to increased area since, in aquaculture, basin depths are generally relatively constant at 1 to 2 metres. Moreover, TSS removal is highly correlated with area.

Interestingly, basin depth was found to be highly correlated with enhanced removal of DP (P=.037) and TKN (P=.049). No correlation exists, however, between depth and total suspended solids removal (P=.186), supporting the concept that particulate matter in aquaculture effluents exhibits discrete settling behaviour. Lastly, a significant negative correlation (P=.028) exists between average fish size and TSS removal, suggesting that solids removal is facilitated in production units rearing larger fish (Exhibit 5.3).

5.3 Chapter Summary - Principal Findings

5.3.1 All four different treatment facility designs display similar treatment efficiencies; moreover, all performed relatively poorly with respect to TSS and TP removal.

5.3.2 Poor performance is likely tied to a combination of operational and design flaws; namely, excessive overflow rates and outlet weir rates, and improper inlet/outlet structures. Given high design overflow rates and for the most part only poor to good treatment facilities, the applicable scaling factor for determination of an appropriate performance overflow rate becomes quite large and, consequently, poor treatment efficiency is expected.

5.3.3 Pond facilities were observed to have the lowest mean overflow rate, and the highest mean removal efficiency for TSS. Additionally, however, they also have the highest mean outlet weir rate at approximately 10 times the recommended value.

5.3.4 TSS removal is inversely proportional to design overflow rate, thereby confirming that reduced overflow rates improve treatment efficiency. Similarly, surface area is directly proportional to treatment efficiency, which confirms the previous statement.

5.3.5 As suspected, TSS removal is also significantly correlated with average fish size, indicating that solids removal is enhanced when larger fish are cultured. The smaller feed and fecal pellets associated with small fish reduce settling velocities and, therefore, make effluent treatment via sedimentation somewhat more difficult. Given similar hydraulic flows and production intensities, a system producing small fish will require a larger settling facility (area) to achieve the same level of performance as an operation raising large fish.

Exhibit 5.1:
Definition and units of measure for 17 effluent treatment variables observed and recorded during site visits. The abbreviated name used in the results section is also presented.

Variable Name	Units	Abbr.	Definition
Design/Operational Variables			
Settling Area	(m^2)	AREA	Total surface area of the settling unit.
Hydraulic Load	(m^3/d)	Q	Total water flow through treatment unit on a daily basis.
Overflow Rate	($m^3/m^2/d$)	Vo	Calculated; Vo = Q/AREA.
Inlet Area	(m^2)	INLET	Cross sectional area of inlet zone of the settling unit.
Outlet Weir Rate	($m^3/m/d$)	OWR	Daily volumetric flow of water per unit length of outlet weir.
Hydr. Ret'n Time	(min)	HRT	Theoretical retention time of water in settling unit.
Depth	(m)	DEPTH	Average depth of settling unit.
Slope of CDC	--	mCDC	Slope of cumulative distribution solids settling curve.
Intercept of CDC	--	INTPT	Intercept of cumulative distribution solids settling curve.
Fish Size	(g)	SIZE	Average weight of individual fish in prod'n unit feeding settling unit.
Water Chemistry Variables			
Tot. Susp. Solids	--	TSS	These data are dimensionless. They are ratios of the effluent concentration of the parameter to the influent concentration. A number less than 1.0 indicates a net loss of that parameter via settling.
Tot. Kjeldahl N	--	TKN	
Total Phosphorus	--	TP	
Diss. Phosphorus	--	DP	

CANADIAN AQUACULTURE SYSTEMS

Exhibit 5.2:
ANOVA table of mean design/operational factors and treatment efficiency for in-raceway, external rectangular, external circular and pond settling basins at intensive salmonid culture facilities. Figures having the same superscript are not significantly different.

Variable	In-raceway (n=11)	Ext. Rect. (n=5)	Ext. Circ. (n=8)	Ponds (n=9)	F Ratio	Prob.
Design/Operational Variables						
Basin Area (m^2)	27.4^a	29.9^a	28.9^a	1656.4^b	16.78	0.000
Hydraulic Load (m^3/d)	6251^a	1486^{ab}	1060^b	20007^a	5.595	0.004
Overflow Rate ($m^3/m^2/d$)	269.5^a	85.9^a	344.3^a	18.7^b	9.501	0.000
Inlet Area (m^2)	3.17^a	0.96^b	0.30^b	0.95^b	11.64	0.000
Out. Weir Rate ($m^3/m/d$)	2062^a	1081^{ab}	945^b	4998^a	4.002	0.017
Hydr. Ret'n Time (min)	9.75^a	27.7^a	42.1^a	260.0^b	10.13	0.000
Basin Depth (m)	0.93^a	0.72^a	1.08^a	1.73^b	5.406	0.004
Slope CDC	.6210	.7851	.8253	.5731	1.994	0.137
Intercept CDC	.0057	.0871	.1639	.1300	0.297	0.827
Average Fish Size (g)	216	242	159	52	3.433	0.030
Effluent Treatment Efficiency Variables (see Note)						
Tot. Susp. Solids	0.705	0.683	0.845	0.694	0.162	0.921
Tot. Kjeldahl N	0.894	0.999	0.816	0.908	0.453	0.717
Total Phosphorus	0.992	0.617	1.016	0.883	0.819	0.494
Diss. Phosphorus	1.569	1.808	1.067	1.001	1.503	0.235

Note: Effluent treatment efficiency variables are dimensionless values; they represent the ratio of effluent to influent concentrations. A number less than 1.0 signifies a net loss of that contaminant from the effluent.

Exhibit 5.3:
Matrix of correlation coefficients and statistical probabilities (P) between sedimentation unit design/operations factors and treatment efficiency with respect to four water quality parameters (n=33).

Design & Operating Parameters \ Water Chemistry Parameters	TSS	TKN	TP	DP
AREA	-.2388 P= .090	-.0999 P= .290	-.0936 P= .302	-.1328 P= .231
Q	-.1301 P= .235	-.0619 P= .366	-.0707 P= .348	-.0591 P= .372
Vo	.3818 P= .014	.1186 P= .255	.1327 P= .231	.1694 P= .173
INLET	-.1819 P= .155	.0088 P= .481	.0229 P= .450	.3878 P= .013
OWR	.0397 P= .417	.1306 P= .234	-.0310 P= .432	-.0309 P= .432
HRT	-.3419 P= .026	-.2489 P= .081	-.1943 P= .139	-.2975 P= .046
DEPTH	-.1429 P= .214	-.2929 P= .049	-.1150 P= .262	.3154 P= .037
mCDC	.2040 P= .127	-.0822 P= .325	.0624 P= .365	.0210 P= .454
INTPT	-.1074 P= .276	.0354 P= .423	.1746 P= .166	.0489 P= .393
SIZE	-.3360 P= .028	-.2419 P= .088	-.1825 P= .155	.1618 P= .184

N.B. A negative correlation coefficient implies improved treatment efficiency due to an increase in the corresponding design/operations variable. Recall that the treatment data are ratios of effluent/influent concentrations.

6.0 IMPLEMENTATION OF AQUACULTURE EFFLUENT TREATMENT

6.1 Commercial Fish Production Facilities in New Brunswick & Ontario

Throughout New Brunswick and Ontario, three principal fish culture production units exist, and the decision to construct one over the others is generally based upon the individual preference of the aquaculturist. Circular tanks are often selected for their self-cleaning qualities; standard raceways for their ease of management; oval raceways for their reduced concrete content and the perceived benefits of extended water use.

Throughout the investigation oval raceway production facilities have consistently stood out as unique production facilities, different from standard raceway and circular tank operations with respect to several production and water quality parameters. Oval raceways generally incorporate a larger production area, utilize more water reuse, and produce an effluent of poorer quality than the other production units (Exhibit 4.5). Similarly, New Brunswick circular tank operations have distinctive features which differentiate them from Ontario farms. Such features include production of smaller sized fish and less intensive production intensities (Exhibit 4.5). Most notably, however, is the significantly slower rate of solids settling in New Brunswick salmon smolt production operations. The average solids settling curve for New Brunswick farms has a higher elevation than the curves for Ontario farms (Exhibit 4.7).

Among Ontario farms, the solids settling curve for oval raceways has a significantly greater elevation than other farm types (Exhibit 4.7), implying that solids removal via settling is more difficult in these facilities than in standard raceways and Ontario circular tank operations. From a productivity perspective, however, oval raceway systems seem to offer no additional benefits. Most importantly, these units do not offer extended water use. That is, productivity, in terms of carrying capacity of fish per unit water flow (kg/Lps), is statistically similar in standard raceways, oval raceways, and Ontario circular tanks (Exhibit 4.5).

In all culture facilities examined, culture intensity (kg fish/Lps), standing crop (kg fish), and average fish size (g) are significantly correlated with many aspects of effluent quality (Exhibit 4.6). Intuitively, this is logical since an increase in any one of these factors necessarily translates to an increase in feed ration and, consequently, poorer water quality. Feed input <u>is</u> responsible for deterioration of water quality. Therefore, feeding strategies must be considered as an important management tool for effluent quality control. While feed presents the source of the pollution problem, specific feed-related factors (i.e. feed brand and type, and feeding method) were not found to impact upon the quality of effluent or effectiveness of treatment. While this may not be entirely plausible, it does suggest that feed-related factors are subordinate to the polluting influence of facility design and culture management practice.

6.2 Design of Effluent Treatment Facilities for Intensive Salmonid Aquaculture

For most commercial-scale intensive salmonid aquaculture operations, solids removal via gravity settling remains the best available technology. Moreover, since total phosphorus concentration and removal is significantly correlated with total suspended solids concentration and removal (Mudrak 1981; Stechey 1988; Appendix III), gravity settling is also recommended for reduction of effluent concentrations of phosphorus. Specific phosphorus removal technologies (i.e. addition of metal-salts, chemical polymers, and/or lime to promote phosphorus precipitation; biological uptake into cell tissue) are not warranted in aquaculture due to the dilute nature of the wastewater stream and the relative expense of these processes.

Overflow Rate. As stated in Section 3.2.4, overflow rate (Vo) must be the foundation of design for solids settling units. Based upon the cumulative distribution curves for solids settling in all four groups of production units, relationships between overflow rate and solids removal efficiency have been projected (Exhibit 6.1). The UMA Engineering study (1988) recommends design overflow rates ranging between 40 and 80 $m^3/m^2/d$ for intensive salmonid culture operations. This means that, for every imperial gallon of water flowing through the treatment unit each minute (IGPM), 0.88 to 1.75 square feet of settling basin surface area must be provided. Theoretically, for overflow rates in this range, TSS removal efficiency varies between 86% and 94% for most Ontario farms. For New Brunswick operations, however, the efficiency is much poorer, averaging only 54% to 65% over this same range of overflow rates (Exhibit 6.1). Farm 91, though, which is the only New Brunswick farm that uses moist feeds, displays solids settling performance which is quite similar to that attained in Ontario production facilities.

Recall, however, that turbulence must be accounted for in design by applying an appropriate scaling factor (Exhibit 3.4). In reality then, solids removal in the ranges presented above is unlikely. For theoretical solids removal efficiencies in the 85% to 95% range, and assuming that basin design and performance is "very good," the data in Exhibit 3.4 recommend that a scaling factor between 2.2 and 3.6 be applied. Similarly, for New Brunswick farms with projected removal efficiencies in the 55% to 65% range a scaling factor of 1.3 should be applied. The net result will be a reduced efficiency rating for the design overflow rate. Consider the following example.

Let's assume that a lined external rectangular clarifier has been designed for an average New Brunswick smolt production operation, and that proper inlet and outlet structures are included. Furthermore, let us assume that the unit has a <u>design overflow rate</u> equal to 40 $m^3/m^2/d$ (0.046 cm/s) based upon the actual surface area of the settling basin and the hydraulic flow, and that the design is "very good." In theory, the curve in Exhibit 6.1 suggests that TSS removal efficiency will equal 66.2%. From Exhibit 3.4, however, we determine that a scaling factor of 1.3 must be used to adjust this performance projection. Consequently, the <u>performance overflow rate</u> is more appropriately equal to 0.060 cm/s (0.046 x 1.3) or 52 $m^3/m^2/d$. Going back to the plot in Exhibit 6.1, we see that, in reality, the projected efficiency of this system is closer to 62%, a

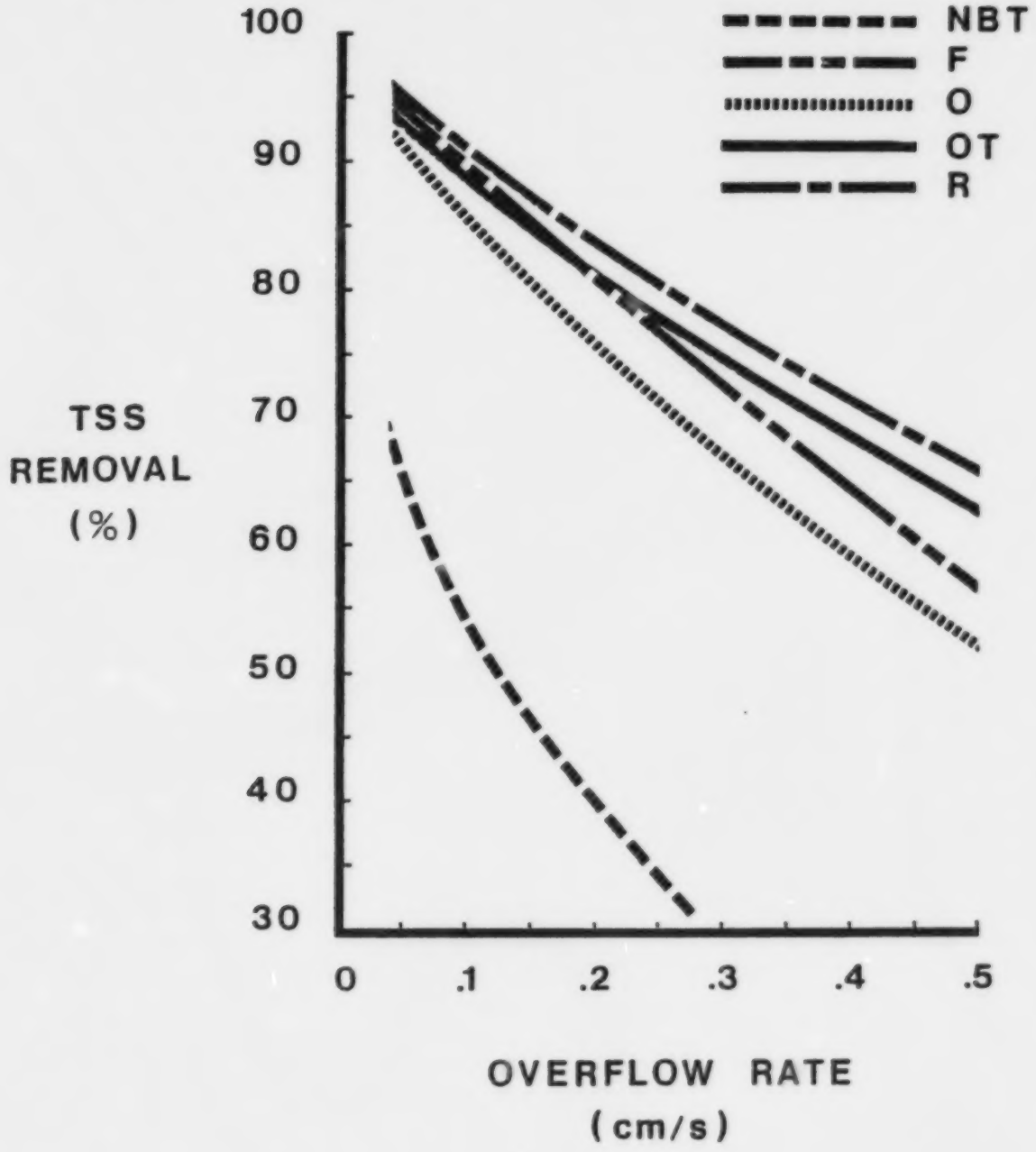

Exhibit 6.1:
Theoretical average performance curves for efficiency of total suspended solids removal via gravitational settling from the discharged effluent of different intensive salmonid culture facilities. R = standard raceways; O = oval raceways; OT = Ontario circular tanks; NBT = New Brunswick circular tanks; F = Farm 91.

reduction of more than 4%. The higher the efficiency, the greater the reduction due to scaling.

Therefore, when designing settling basins for aquaculture operations, an iterative approach is necessary:

(1) The surface area required for settling is calculated based upon the design overflow rate (see Section 6.4) and the hydraulic loading rate of the operation.

(2) The theoretical efficiency of this design is determined using the data plotted in Exhibit 6.1 for the appropriate fish culture facility.

(3) A scaling factor must be selected from Exhibit 3.4, based upon this design. This scaling factor is used to adjust the design overflow rate to enable a realistic projection of basin efficiency.

(4) If the effectiveness of solids removal is too inefficient to meet effluent discharge criteria, then the process must be repeated from Step 1 using a lower overflow rate.

At existing operations, the design overflow rate can be calculated by dividing the area of the settling basin into the hydraulic flow rate of the basin. Then, using the appropriate curve in Exhibit 6.1, a theoretical removal rate can be determined for the treatment facility. Next, using Exhibit 3.4, an appropriate scaling factor can be selected to calculate the performance overflow rate, and to project a more realistic level of efficiency. Experiential judgement will be required to classify the overall level of basin performance such that an appropriate scaling factor from Exhibit 3.4 can be selected and applied. If the projected level of efficiency is insufficient to meet discharge criteria, the area of the settling basin will need to be increased (or the hydraulic load decreased) to improve performance.

In all settling basins, the average horizontal fluid flow velocity must be maintained below 2 to 4 cm/s to ensure that scour problems do not arise.

Inlet Structures. Proper inlet design is critical for minimization of inlet velocity, turbulence, and hydraulic short-circuiting. The specific design of the inlet structure, however, will depend upon the type of treatment facility being used. In all cases, the inlet should be designed such that fish from the production area of the culture facility do not enter the settling basin(s).

For in-raceway settling basins, there is no need for an inlet structure, *per se*. Instead, simply screening off a section of the raceway at the downstream end provides for effective introduction of water to the quiescent settling zone. It is imperative, however, that all air diffusers be kept upstream of the fish retaining screen at a distance of approximately 2 times the depth of the water column. This is necessary since the rising air bubbles create large convective cells having a circular mixing motion over this region. The screen material

(usually semi-rigid plastic) must be sufficiently small to restrict the passage of fish into the settling zone.

If external rectangular basins are used, it is important to distribute the inlet flow across the entire width of the basin, and to achieve this with minimal energy input. A submerged, wide-top weir with chamfered edges, which extends across the full width of the settling basin, is most appropriate. The degree of submergence should be approximately 15% of the basin depth; i.e. in a 1 metre deep basin, the weir should be 85 cm tall. Since some turbulence is still introduced with this inlet structure, the settling zone should be lengthened to account for any reduction in efficiency due to the inlet. A typical length increment is equal to the basin depth.

For external circular basins, process water should enter the basin at the centre, ideally from below the basin floor. The inlet pipe should be enclosed within a concentric perforated baffle, designed to reduce inlet velocity and distribute the flow radially through the full depth of the basin. The inlet turbulence can be accounted for by adding 0.25 times the basin depth to the basin diameter. Moreover, since circular tanks come in standard sizes, the designer of a circular settling basin will be wise to use the standard tank size which is larger than that recommended in design calculations, as opposed to a tank slightly smaller than required.

Outlet Structures. For all settling basins, an overflowing outlet weir is most appropriate for gently drawing off clarified effluent from the treatment unit. This structure must be designed such that the clear water is skimmed off the top of the basin; hence the overflow design. To minimize the entrainment of fine particulate material in the rising discharge flow, it is important to maximize the length of the outlet weir.

For in-raceway and rectangular settling basins, at a minimum the weir must extend across the entire width of the basin. The outlet weir rate (m^3/m/d or IGPM/foot weir length) can be measured and used as an indicator of the entrainment effect. If the weir rate is greater than 400 m^3/m/d (18.6 IGPM/ft), then the settling zone should be lengthened by 1.5 times the basin depth in compensation. For weir rates between 350 and 400 m^3/m/d (16.3 to 18.6 IGPM/ft), the additional length requirement is 1.3 times basin depth, and for weir rates below 350 m^3/m/d (16.3 IGPM/ft), the added length need only be equal to the basin depth. Finally, in circular settling basins, the overflow weir should extend around the periphery of the basin. Since the circumference of circular tanks is large in relation to the width of similarly sized rectangular basins, compensation for outlet entrainment effects is generally not required in circular basins.

In most existing effluent treatment facilities, overflow standpipes are used for outlet structures. These can be readily upgraded at minimal expense. Two alternatives exist. Placement of an overflow weir constructed of damboards or stoplogs immediately upstream of the standpipe will provide the necessary weir. To ensure an overflow action, the damboards should be used to control basin water level and the standpipe should be cut approximately 6 to 10 cm shorter. Alternatively, a T-fitting can be placed over top of the existing stand

pipe. From each end of the T, a halved pipe is cemented into place, extending from one side of the basin to the other. This configuration essentially provides a double-width weir, since water now overflows on both the upstream and downstream sides of the halved pipe. Effluent is still discharged through the standpipe as before. In adapting overflow weirs, however, care must be taken to ensure that the weir is level, thereby ensuring that water flow is uniform across the entire weir length.

6.3 Projected Production of Phosphorus and Solids from Intensive Salmonid Culture Facilities

Operations data collected during the field study have provided a quantitative understanding of standing crop biomass and fish production intensity based upon water use. Production intensity represents the weight of fish in the tank per unit water flow (kg fish/litre per second of source water flow). Standing crop is the average total weight of fish in the production unit(s). These field data can be applied, in conjunction with the waste production factors defined in Section 1.2, to project average daily concentrations of TSS, TP, and DP in untreated fish production effluent. Moreover, projections can be generated for the four groups of production facilities.

For each group, the average standing crop (kg fish) was used as a starting point. For Ontario operations, a feeding rate of 1.2% body weight per day was assumed, based on production data which show that the average size of individual fish ranged between 204 and 340 grams, and was not significantly different ($P>0.05$) between groups. For New Brunswick smolt production operations, an average feed rate of 1.5% body weight per day is more appropriate for 28 gram fish; this figure has been applied in calculations. The mean production intensity, and the 95% confidence limits around this mean, were incorporated into the model as an indication of the variability in production intensity. From these data, an average influent flow rate was calculated, and then, using the waste production factors for TSS, TP, and DP, average daily concentrations of these pollutants in the production effluent were projected. These projected values are compared with observed values in Exhibit 6.2.

For all groups, variability exists between observed and expected concentrations of pollutants in the effluent. For the most part, variability is greater for total and dissolved phosphorus than for solids concentrations. In some cases, projected values are two- to three-fold greater than observed values. Solids modelling is reasonably accurate for standard raceways and both Ontario and New Brunswick circular tanks, but it over-estimates the concentration of effluent solids in oval raceways. Conversely, phosphorus modelling is reasonably accurate for oval raceways, but is over-estimated in standard raceways and Ontario circular tanks. Among the four groups, the model appears most accurate for New Brunswick circular tank operations (Exhibit 6.2).

Oval raceways produce the highest expected concentration of TSS, TP, and DP among the four groups while New Brunswick tank operations produce the lowest concentrations. Observed data confirm that TP and DP concentrations are significantly higher ($P<0.006$) in oval raceway operations than in all other groups (Exhibit 4.5). New Brunswick circular tank operations were observed to

produce effluent concentrations of TSS which are significantly lower than all other groups ($P=0.0239$). There is no difference ($P>0.05$) in the effluent concentration of TSS among the remaining three groups (Exhibit 4.5).

Possible factors which contribute to the variability between predicted and observed values may include the use of "intensity" as a model input. In group comparisons, production intensity was not found to differ between groups ($P=0.4320$), however, individual groups means were incorporated into the model. As well, for individual pollutants, the reliability of the waste production factors may be suspect, especially for phosphorus. Solids modelling is comparatively simple; the only critical factor is the overall digestibility of the diet -- a component which is well quantified by feed manufacturers. Total and dissolved phosphorus production, however, is largely influenced by the quality and quantity of phosphorus in the diet, which is subject to change due to variations in feed ingredients. Moreover, the range of production factors for phosphorus compounds in published literature is greater than that for total suspended solids, thereby affirming the complexity of nutrient load modelling. Lastly, the assumption of feeding rates (i.e. 1.2% and 1.5% body weight per day) is valid for modelling, however, one cannot assume that this feed rate was applied in all fish culture facilities on the specific days when field samples were collected.

Assuming, however, that these modelled waste production figures present best available data, then these data can be applied in conjunction with effluent treatment efficiency figures to generate numbers reflecting the anticipated quality of final discharged effluent from aquaculture operations. The data provided in Exhibit 6.2 offer a margin for error since, for nearly all pollutants and fish culture facilities, the projected values are greater than those values observed during field monitoring.

6.4 Projected Performance of Effluent Treatment Facilities

When the nature and composition of aquacultural wastes are considered in design, aquacultural treatment systems can be particularly effective in clarification of discharged effluent. Moreover, since the removal of total phosphorus is positively correlated with removal of suspended solids, a reduction in the latter necessarily translates into a reduction in the former.

Operational data from existing fish hatchery treatment units in the United States have been compiled (Exhibit 6.3). Settleable solids (SS) removal in excess of 90% is readily achieved, and greater than 80% removal of total suspended solids (TSS) is reported (Mudrak 1981; McLaughlin 1981). Note that the design overflow rates for these facilities range between 21.4 and 120.0 $m^3/m^2/d$ (0.025 to 0.139 cm/s). Total phosphorus removal via sedimentation in concrete clarifiers is reported for three fish culture stations in Pennsylvania. Oswayo FCS, Tionesta FCS, and Big Spring FCS report average reductions of total phosphorus in discharged effluent equalling 62%, 68%, and 77%, respectively (Mudrak and Stark 1981; Mudrak 1981).

Exhibit 6.2:
Projected and observed concentrations of TSS, TP, and DP in untreated fish culture. Data for standing crop and production intensity are from field observations.

	Lower C.L.	Mean	Upper C.L.
STANDARD RACEWAYS			
Standing Crop (kg)		10417	
Feeding Rate (% body weight/day)		1.2	
Daily Feed Ration (kg)		125.0	
Production Intensity (kg/Lps)	99.1	202.3	305.5
Average Flow Rate (Lps)	105.1	51.5	34.1
TSS Prod'n @ 300 g/kg Feed (kg)	37.50	37.50	37.50
Projected Avg. Daily [TSS] (mg/L)	4.13	8.43	12.73
Observed [TSS] (mg/L)	4.20	7.01	9.82
TP Prod'n @ 7.6 g/kg Feed (kg)	0.950	0.950	0.950
Projected Avg. Daily [TP] (mg/L)	0.105	0.214	0.322
Observed [TP] (mg/L)	0.053	0.077	0.102
DP Prod'n @ 2.2 g/kg Feed (kg)	0.275	0.275	0.275
Projected Avg. Daily [DP] (mg/L)	0.030	0.062	0.093
Observed [DP] (mg/L)	0.012	0.027	0.041
OVAL RACEWAYS			
Standing Crop (kg)		8216	
Feeding Rate (% body weight/day)		1.2	
Daily Feed Ration (kg)		98.6	
Production Intensity (kg/Lps)	196.9	372.1	547.4
Average Flow Rate (Lps)	41.7	22.1	15.0
TSS Prod'n @ 300 g/kg Feed (kg)	29.58	29.58	29.58
Projected Avg. Daily [TSS] (mg/L)	8.20	15.50	22.81
Observed [TSS] (mg/L)	4.18	7.08	9.97
TP Prod'n @ 7.6 g/kg Feed (kg)	0.749	0.749	0.749
Projected Avg. Daily [TP] (mg/L)	0.208	0.393	0.578
Observed [TP] (mg/L)	0.138	0.354	0.570
DP Prod'n @ 2.2 g/kg Feed (kg)	0.217	0.217	0.217
Projected Avg. Daily [DP] (mg/L)	0.060	0.114	0.167
Observed [DP] (mg/L)	0.072	0.121	0.170

Exhibit 6.2: (cont'd)
Projected and observed concentrations of TSS and TP in untreated fish culture effluent. Data for standing crop and fresh water intensity are from field observations.

	Lower C.L.	Mean	Upper C.L.
ONTARIO CIRCULAR TANKS			
Standing Crop (kg)		996	
Feeding Rate (% body weight/day)		1.2	
Daily Feed Ration (kg)		12.0	
Production Intensity (kg/Lps)	130.5	266.9	403.2
Average Flow Rate (Lps)	7.6	3.7	2.5
TSS Prod'n @ 300 g/kg Feed (kg)	3.59	3.59	3.59
Projected Avg. Daily [TSS] (mg/L)	5.44	11.12	16.80
Observed [TSS] (mg/L)	4.73	11.15	17.56
TP Prod'n @ 7.6 g/kg Feed (kg)	0.091	0.091	0.091
Projected Avg. Daily [TP] (mg/L)	0.138	0.282	0.426
Observed [TP] (mg/L)	0.039	0.158	0.277
DP Prod'n @ 2.2 g/kg Feed (kg)	0.026	0.026	0.026
Projected Avg. Daily [DP] (mg/L)	0.040	0.082	0.123
Observed [DP] (mg/L)	0.012	0.032	0.052
NEW BRUNSWICK CIRCULAR TANKS			
Standing Crop (kg)		6973	
Feeding Rate (% body weight/day)		1.5	
Daily Feed Ration (kg)		104.6	
Production Intensity (kg/Lps)	36.6	76.5	116.3
Average Flow Rate (Lps)	190.5	91.2	60.0
TSS Prod'n @ 300 g/kg Feed (kg)	31.38	31.38	31.38
Projected Avg. Daily [TSS] (mg/L)	1.91	3.98	6.06
Observed [TSS] (mg/L)	0.95	2.79	4.62
TP Prod'n @ 7.6 g/kg Feed (kg)	0.795	0.795	0.795
Projected Avg. Daily [TP] (mg/L)	0.048	0.101	0.153
Observed [TP] (mg/L)	0.054	0.109	0.164
DP Prod'n @ 2.2 g/kg Feed (kg)	0.230	0.230	0.230
Projected Avg. Daily [DP] (mg/L)	0.014	0.029	0.044
Observed [DP] (mg/L)	0.028	0.052	0.076

Regression analysis of the data presented by Mudrak (1981) for total suspended solids and total phosphorus removal provides the following relationship:

$$\% \text{ TP Removal} = 0.838 \times \% \text{ TSS Removal} - 4.679 \qquad r^2 = 0.936 \quad (n=9)$$

Using the TSS and TP production rates in New Brunswick and Ontario fish culture operations (see Exhibit 6.2), and applying the removal efficiencies for TSS in properly designed clarifiers (see Exhibits 3.4 and 6.1), the likely concentration pollutants in discharged effluents from commercial fish culture operations can be projected (Exhibit 6.4).

The province of New Brunswick is currently in the process of establishing effluent discharge guidelines for fish culture and, consequently, the Ontario Interim Guidelines[5] are frequently referred to by New Brunswick abatement officers for guidance. Due to the total volume of water used in New Brunswick smolt production operations, and the relatively small size of the salmon smolts (and hence the relatively low daily feed ration which is based upon a percentage of total fish biomass), effluent concentrations of total suspended solids and total phosphorus are, for the most part, within the limits laid out in the Ontario guidelines. In fact, the quality of untreated farm effluent at 7 of the 11 farms visited during the New Brunswick field survey was adequate to meet Ontario discharge guidelines without treatment.

For New Brunswick farms, treatment facilities designed to operate with an overflow rate of 86.4 $m^3/m^2/d$ (0.50 cm/s) will, on average, discharge only 2.03 mg TSS/l and 0.064 mg TP/L (Exhibit 6.4). When settling area is increased to accomodate a design overflow rate of 25.9 $m^3/m^2/d$, both TSS and TP discharge concentrations will generally be within the Ontario design standards (i.e. < 5 mg TSS/L and < 0.05 mg TP/L). Recall that the design standards are twice as stringent as the compliance standards. Note, however, that large changes in overflow rate do not account for equally large changes in effluent solids and phosphorus concentrations. This is due to the relatively low initial concentrations of these pollutants and the shape of the solids settling and solids removal performance curves. Moreover, these figures can be expected to change as the average size of fish in the system changes. Given that an average fish weighed approximately 27.5 grams at the time of the study, and that a maximum weighted average smolt size is 97 grams, then these discharge figures may be expected to increase by approximately 50%.

In view of these findings, design overflow rates for treatment facilities at New Brunswick smolt production operations which are less than or equal to 86.4 $m^3/m^2/d$ will generally produce acceptable effluent quality. Based upon field

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[5]Ontario Guidelines state that, for compliance purposes, effluent concentrations of TSS shall not be more than 10 mg/L above background concentrations and TP shall not be greater than 0.10 mg/L under any circumstances. From a design perspective, facilities should be constructed and operated with the intention of producing effluent concentrations less than 5 mg TSS/L and 0.05 mg TP/L.

survey results, design overflow rates less than 25.9 m3/m^2/d are overly stringent and are generally not warranted.

By comparison, in Ontario Rainbow Trout culture operations, it is evident that the effluent concentration of total phosphorus is the limiting factor governing the necessary level of efficiency for aquaculture wastewater treatment facilities. Over the range of design overflow rates examined in Exhibit 6.4 (i.e. 43.2 to 86.4 $m^3/m^2/d$), an average standard raceway, oval raceway, or circular tank operation will meet the 10 mg/L discharge criterion for TSS. Over this same range of overflow rates, however, only standard raceway operations will achieve the 0.10 mg/L non-compliance limit for total phosphorus discharge. In fact, an average standard raceway operation will achieve compliance limits at design overflow rates as high as 167 $m^3/m^2/d$ (0.193 cm/s), producing daily average discharge concentrations of TSS and TP equal to 2.6 and 0.100 mg/L, respectively. Circular tank operations reach a ceiling at a design overflow rate of approximately 65 $m^3/m^2/d$, producing a daily average discharge concentration equal to 0.099 mgTP/L.

Oval raceway facilities, once again, produce the poorest quality effluent and, therefore, require comparatively larger treatment facilities. The data presented in Exhibit 6.4 suggest that an average oval raceway operation will not produce a final effluent within compliance limits for TP at design overflow rates as low as 43.2 $m^3/m^2/d$ (0.05 cm/s). However, if one considers the observed concentrations of TP in untreated effluent at oval raceway operations and, furthermore, if the single largest observation is removed from the data set, the mean concentration of TP in oval raceway effluent falls to 0.279 mg/L. Assuming that this is representative of oval raceway operations, 64.2% of the TP must be removed to achieve the compliance limit. This requires that 82.2% of the TSS be removed, which corresponds to a design overflow rate of 49.3 $m^3/m^2/d$ (0.057 cm/s).

Therefore, in Ontario production facilities, the recommended design overflow rate should be less than 167 $m^3/m^2/d$ (0.193 cm/s) for standard raceway operations and less than 64.8 $m^3/m^2/d$ (0.075 cm/s) for circular tank fish culture operations. This value should not exceed 40.0 $m^3/m^2/d$ (0.046 cm/s) for oval raceway production units. At these rates, the effluent concentration of total phosphorus is projected to be marginally below the non-compliance limit of 0.10 mgTP/L.

These data are presented in the following table, along with conventional flow and area terminology for ease of implementation. Note that these data assume the use of groundwater or spring water sources having a negligible influent concentration of total phosphorus. The maximum design overflow rates for fish farms utilizing surface waters will be greater, ultimately depending upon the background concentration of total phosphorus. In extremely delicate environments, the mass load of phosphorus and total suspended solids should be used as the basis for effluent concentration limits.

Recommended Design Overflow Rates
For Four Culture Systems

Culture System	Design Vo ($m^3/m^2/d$)	Settling Rate (cm/s)	Req'd Area (ft^2/IGPM)
Standard Raceway	167	0.193	0.42
Oval Raceway	40	0.046	1.76
Ont. Tank	65	0.075	1.08
N.B. Tank	86	0.100	0.82

Since these values represent industry-wide recommendations for average facilities, specific overflow rates may necessitate fine tuning at individual aquaculture facilities to maximize performance. Routine water quality assessment for TSS and TP will be required to permit treatment unit adjustment. In all cases, to achieve optimum performance, it is imperative to compensate for inlet and outlet structure effects by increasing the length of the settling basin as required, over and above the area requirement defined by hydraulic loading and overflow rate. Refer to Section 6.2 for additional length requirements for specific settling basin designs.

Exhibit 6.3:
Efficiency of solids sedimentation for removal of settleable solids (SS), total suspended solids (TSS), and total phosphorus (TP) from intensive trout culture effluent.

Site	Design Overflow Rate ($m^3/m^2/d$)	% Removal SS	TSS	TP	Source
Lamar NFH	120.0	90.0	na	na	McLaughlin 1981
Jordan River NFH	58.7	79.2	65.8	na	"
Jones Hole NFH	57.5	91.2	90.0	na	"
Oswayo FCS	69.7	97.8	87.3	65.6	Mudrak 1981
Tionesta FCS	40.5	99.1	88.9	68.2	"
Big Spring FCS	21.4	99.0	88.0	76.7	"

CANADIAN AQUACULTURE SYSTEMS

Exhibit 6.4:
Projected performance of settling basins at intensive Rainbow Trout culture operations in Ontario at different overflow rates and assuming "very good" basin design.

DESIGN PARAMETERS

Scale-up Factor[1]	Design Overflow Rate[2] $m^3/m^2/d$	cm/s	Performance Overflow Rate[3] $m^3/m^2/d$	cm/s
2.2	43.2	0.050	95.0	0.110
2.2	64.8	0.075	142.6	0.165
2.2	86.4	0.100	190.1	0.220

PERFORMANCE PARAMETERS - STANDARD RACEWAYS

Untreated Effluent[4] mgTSS/L	mgTP/L	Design Overflow Rate $m^3/m^2/d$	cm/s	% Removal TSS	TP	Effluent Conc'n mgTSS/L	mgTP/L
8.43	0.214	43.2	0.050	89.5	70.3	0.89	0.064
8.43	0.214	64.8	0.075	85.5	67.0	1.22	0.071
8.43	0.214	86.4	0.100	81.5	63.6	1.56	0.078

PERFORMANCE PARAMETERS - OVAL RACEWAYS

Untreated Effluent[4] mgTSS/L	mgTP/L	Design Overflow Rate $m^3/m^2/d$	cm/s	% Removal TSS	TP	Effluent Conc'n mgTSS/L	mgTP/L
15.50	0.393	43.2	0.050	84.5	66.1	2.40	0.133
15.50	0.393	64.8	0.075	78.5	61.1	3.33	0.153
15.50	0.393	86.4	0.100	73.5	56.9	4.11	0.169

PERFORMANCE PARAMETERS - ONTARIO CIRCULAR TANKS

Untreated Effluent[4] mgTSS/L	mgTP/L	Design Overflow Rate $m^3/m^2/d$	cm/s	% Removal TSS	TP	Effluent Conc'n mgTSS/L	mgTP/L
11.12	0.282	43.2	0.050	87.5	68.6	1.39	0.089
11.12	0.282	64.8	0.075	83.0	64.9	1.89	0.099
11.12	0.282	86.4	0.100	79.0	61.5	2.34	0.109

1 Scale-up Factor = 2.2; i.e. theoretical removal efficiency of approx. 85% in basins with "very good" design (see Exhibit 3.4).
2 Design Vo based on hydraulic load and required surface area.
3 Performance Vo based on scaling factor turbulence adjustment (see Exhibit 6.1).
4 Projected values (see Exhibit 6.2).

Exhibit 6.4: (cont'd)
Projected performance of settling basins at intensive Atlantic Salmon smolt culture operations in New Brunswick at different overflow rates and assuming "very good" basin design.

DESIGN PARAMETERS

Scale-up Factor[1]	Design Overflow Rate[2] $m^3/m^2/d$	cm/s	Performance Overflow Rate[3] $m^3/m^2/d$	cm/s
1.3	25.9	0.030	33.7	0.039
1.3	43.2	0.050	56.2	0.065
1.3	86.4	0.100	112.3	0.130

PERFORMANCE PARAMETERS - NEW BRUNSWICK CIRCULAR TANKS

Untreated Effluent[4] mgTSS/L	mgTP/L	Design Overflow Rate $m^3/m^2/d$	cm/s	% Removal TSS	TP	Effluent Conc'n mgTSS/L	mgTP/L
3.98	0.101	25.9	0.030	67.5	51.9	1.29	0.049
3.98	0.101	43.2	0.050	61.0	46.4	1.55	0.054
3.98	0.101	86.4	0.100	49.0	36.4	2.03	0.064

1 Scale-up Factor = 1.3; i.e. theoretical removal efficiency of approx. 65% in basins with "very good" design (see Exhibit 3.4).
2 Design Vo based on hydraulic load and required surface area.
3 Performance Vo based on scaling factor turbulence adjustment (see Exhibit 6.1).
4 Projected values (see Exhibit 6.2).

CANADIAN AQUACULTURE SYSTEMS

6.5 Management Strategies for Effective Effluent Quality Control

Management strategies must address the issue of fish farms as sources of aquatic pollution on four principal fronts: feed and feeding practices, rearing unit design, solids settling unit design, and solids removal and disposal. All four of these factors are necessarily inter-related. A chain is only as strong as its weakest link and, therefore, pollution must be challenged on all fronts if abatement is to be effective.

6.5.1 Feed and Feeding Practices

Feed is ultimately the source of pollution in aquaculture. From the feed manufacturers' perspective, R&D efforts must be focused upon the development of commercial feeds which have reduced phosphorus content and higher digestibility. Indeed, on-going research in these areas at nearly every major feed manufacturer and fish nutrition laboratory in North America, Europe and Japan is steadily improving the overall quality of feed.

It is too convenient, however, to blame feed manufacturers for feed-related pollution. The fish culturist can make considerable inroads toward reducing the pollution impact of feeds through the use of wise feeding practices. Moreover, such practices often produce a financial benefit as well. Rough handling and improper storage of feeds promote pellet erosion, resulting in an increased level of fines which cannot be utilized by the fish. Proper storage and handling, therefore, can reduce the pollution impact of feeds and result in less feed wastage. Prior to adding feeds to feed hoppers or troughs, screening the pellets will remove the fines, thus preventing their addition to the water. Feeding practices can also be managed to reduce pollution and improve fish production. A carefully monitored feeding program will enable the fish culturist to select the optimum pellet size for the size of fish in the facility. Feeding of oversized and/or undersized pellets promotes waste, inefficiency due to poorer feed conversion, and pollution. Educational symposia on feeding strategies and programs, sponsored by feed manufacturers and/or university extension offices, would be highly beneficial.

6.5.2 Rearing Unit Design

The results of this study clearly indicate that different designs of fish production facilities have different pollution impact. Selection of those designs which facilitate solids removal and minimize the release of particulate and soluble pollutants should be emphasized in the development of new aquaculture ventures.

In all culture facilities, tank design should facilitate the rapid and gentle removal of waste feed and particulate fecal matter from the water column. The longer these materials remain in suspension, the more they are subject to agitation and, consequently, the smaller they become. These smaller particles are then more difficult to remove from suspension and require substantially larger treatment units to achieve the desired level of efficacy. Additionally, leaching of soluble nutrients is enhanced as particle size decreases.

When designing and constructing culture tanks, it should be borne in mind that production area and the volumetric flow of water are the two most determinant factors governing the carrying capacity (production intensity) of a fish culture system. Furthermore, no difference was observed in average production intensities among New Brunswick or Ontario farms (Exhibit 4.5), however, a comparison of production area among the four groups of farms does reveal significant differences. Clearly then, some culture units may be larger than they need be.

Given a constant water flow rate and tank depth, increased area means that the rate of water movement through the tank is reduced, and slower flow results in more solids settling within the rearing unit where it is not desired. Solids settling within the culture unit hinders solids removal and, hence, increases the solubilization of nutrients. Shallow tanks are recommended to provide good horizontal flow and to promote self-cleaning. In shallower tanks, fish density is higher and thus fish activity, coupled with aeration, generally keeps particulate matter suspended within the water column so that it is carried to the settling unit. For trout production, tank depth should approximate 76 cm (30"); for salmon smolts, 100 cm (39") is more appropriate.

Many existing aquaculture operations can improve solids removal from the culture units by reducing the level of water in the units. In fact, at one highly-intensive facility in Ontario, the shallowing of raceways from 152 cm to 76 cm greatly reduced solids accumulation in the production unit and facilitated daily maintenance procedures, with no reduction in productivity. Standard raceway and circular tank culture systems should be selected in future design considerations due to the quality of discharged effluent observed at these facilities.

By providing protection from the wind blowing across the surface of settling ponds, the efficiency of sedimentation will improve since wind-induced currents will not induce currents which can impair the settling process. Windbreaks or shelterbelts can be living or artificial barriers erected for protection against detrimental winds. The barrier created by a windbreak exerts a drag force on the approaching wind which results in lost momentum and thus a sheltering effect is produced in the lee of the windbreak. The degree of wind speed reduction is a function of windbreak height and permeability. The less permeable the windbreak the less bleed flow through it. This results in a larger drag force and a corresponding upward deflection of the approaching flow (Hagen and Skidmore 1971; Raine and Stevenson 1977).

Reductions in wind speed extending from approximately 8 to 60 times the height of the shelterbelt (8-60H) have been reported. Van Eimern et al. (1964), however, state "the rule of thumb applies, that the sheltered zone reaches up to about 30H in the lee, but that, for a wind reduction of 20 percent or more, only 20H should be reckoned." Several studies (Van Eimern et al. 1964; Baltaxe 1967; Raine and Stevenson 1977) have found that below a critical permeability of approximately 30-35%, windbreaks produce a turbulent wake characterized by strong eddies and reversed flow patterns. At the opposite extreme, Gandemer (1978) found that windbreaks having a permeability in excess of 70% provide essentially no wind protection.

Therefore, for New Brunswick operations, which generally utilize relatively large settling ponds, it may be advisable to install appropriate wind protection around the perimeter of the settling facilities. Where multiple ponds are used, placement of wind protection along the berm between successive ponds may also be beneficial. For each production site, the local wind climate records should be consulted to determine the frequency and direction of prevailing winds to facilitate proper placement of shelterbelts.

6.5.3 Solids Settling Unit Design

The specific requirements for effective solids settling unit design are presented on a micro level in Section 6.2 and will not be repeated here. From a macro level, however, one key issue warrants discussion; that of treatment unit size. Where possible, a number of small treatment units designed to treat a portion of the total process flow is recommended, as opposed to one large treatment unit sized to treat the entire process flow. Small units, such as in-raceway settling basins, are easier to manage and clean. It is more realistic to schedule cleaning of ten smaller basins than one large basin. In each case, the total settling area will be the same, however, cleaning of one small basin as part of a daily or weekly routine can be scheduled more readily than can cleaning the entire large basin. Hence, the smaller units are more manageable.

Where large units are typically used, as in New Brunswick, the treatment facility should be designed and managed such that individual settling basins can be routinely removed from service for cleaning without disrupting operations or adversely affecting effluent quality.

6.5.4 Solids Removal and Disposal

Sedimentation of solid matter from fish culture effluent is only the first step of the effluent treatment process. Once settled to the floor of the settling basin, the accumulated manure must be effectively removed to prevent solubilization of particulate nutrients. It must then be disposed of in an environmentally acceptable manner.

Solids Removal. Vacuuming of settled manure, much the same way that swimming pools are vacuumed, still offers the best method for solids removal. Vacuum heads designed specifically for fish culture are commercially available, or can be easily home-made.

The frequency of vacuum removal must also be addressed since, over time, accumulated solids may become anaerobic at lower layers, resulting in the release of dissolved nutrients. Moreover, Mudrak (1981) reports that aged manure becomes quite viscous and removal is impaired. Before either of these events occur, however, the depth of the manure will certainly increase to a point where basin efficiency is greatly reduced due to lost volume.

Solubilization of dissolved nutrients (especially phosphorus) is most rapid during the first 2 to 3 days after the solid pellet is discharged into the water, and comparatively little solubilization occurs beyond day 4 (Zeigler 1988; Parjala 1984). Consequently, unless the solids had been vacuumed from the settling basins and production facilities within 2 to 3 days prior to site visits, the data collected during this investigation represent steady-state concentrations of dissolved and total phosphorus. As such, so long as effluent compliance criteria are achieved in treated wastewaters, the frequency of solids removal from settling facilities remains somewhat flexible.

In large settling basins, such as those employed in the New Brunswick smolt industry, such frequent cleaning is not practical. In these cases, the temporary withdrawl of individual ponds from on-line settling will be most appropriate. During this time, all flow to the basin is diverted to the other settling units and the entire volume of the off-line basin can be pumped off into transportation tanks or directly onto agricultural land (see *Solids Disposal* below). Under such circumstances, routine sampling of effluent water quality is necessary to monitor effluent concentrations of dissolved nutrients from the facility.

Solids Disposal. There is a Chinese philosophy which states: "substances that by others may be considered wastes are only resources out of place." Such is the case with settled fish manure, which has properties similar to low grade fertilizer. Typical nutrient concentrations in trout culture manure are presented in the following table.

Nutrient Composition of Settled Manure (% dry weight)

	Mudrak & Stark	Willet & Jakobsen
Nitrogen	1.4% to 4.9%	3.30%
Phosphorus	1.5% to 3.0%	1.03%
Potassium	0.2% to 0.7%	0.03%
Organic Carbon	NA	25%
pH	NA	6.31

Consequently, land application of fish manure remains the best solution for disposal. Since the manure is highly liquid (generally less than 5% solids), it can be spread directly onto agricultural land using liquid manure spreaders and/or irrigation pumps. Where agricultural land is not adjacent to the culture facility, the manure will need to be transported to acceptable, near-by sites. Naturally, this solution is only feasible during the agricultural growing season. Throughout the winter months, it is necessary to store the collected manure in a suitable holding facility.

The application of settled fish culture wastes over agricultural land has been successfully demonstrated. While heavy manure loadings can be detrimental to cover crops and can cause severe odour problems, properly managed loadings can be beneficial to vegetative growth. Trout manure has been found to increase the availability and uptake of both nitrogen and phosphorus, and enhances the dry matter yield of crop harvests. No significant increases in the concentration of K, S, Mg, Cu, Zn, Al, B, Fe, Na, Ca, Cd, Cr, Pb, Ni, or Mo were detected in cover crops (Mudrak and Stark 1981; Willet and Jakobsen 1986).

The concentration of nitrogen in settled trout manure is the limiting factor governing land application rates. Pennsylvania experience has shown that, in general, manure can be safely applied over land so long as at least one hectare of land, with good drainage potential, is available for each 9400 m^3/d of flow through the culture system. For mixed grass crops having a nitrogen uptake capacity of 224 kg/ha (200 lbs/Ac), manure application rates should approximate 120 m^3 per hectare (10,600 Imp. gal/Ac), assuming a 5% solids concentration.

6.6 Economics of Effluent Treatment in New Brunswick Smolt Production

Internationally, aquaculture tends to be most profitable in regions where environmental regulatory controls are lax or non-existent (Pruder 1989). This suggests that effluent quality control has an associated cost. Consequently, while any recommendations put forth in this study must necessarily be effective in controlling effluent concentrations of suspended solids and phosphorus, the installation and operation of any wastewater treatment facility must be economically feasible for the industry to adopt. Effluent treatment does not increase productivity and, therefore, the expense associated with effluent treatment must be minimized. Least-cost treatment technologies, based upon simplicity and practicality, must be applied. From a cost/benefit perspective, Parjala (1984) reports that sedimentation technologies present the most realistic methodology for clarifying aquaculture effluents.

Within the context of the New Brunswick smolt production industry, specific economic studies are not readily available in the published literature. Furthermore, while a number of studies are available for trout production (Lewis 1979; Castledine 1986; Stechey and Kantor 1988), these studies are representative of commercial culture of food fish to approximately 0.75 to 1.5 kg each. This information is not directly applicable to smolt production. Within the context of this investigation, interviews have been conducted with managers of New Brunswick smolt production operations to investigate the cost structure of such operations. This information has been used as the basis for this economic assessment. Note, however, that this analysis is not intended to be a comprehensive assessment of the economics of smolt production. Rather, it is presented to offer comparative assessment of the costs of practical effluent treatment operations at intensive smolt production facilities.

The following assumptions have been made in conjunction with this economic study.

1) The analysis has been conducted for a hypothetical farm, having an annual production capacity of 350,000 smolts. This operation should not be construed as a low-cost producer.

2) Water flow has been determined from the average observed rate of water consumption at the eleven facilities visited, adjusted for an annual production of 350,000 fish.

3) Standard 1989 smolt prices are applied. A weighted average price per smolt has been calculated based upon the percentage of production in each size class, and the proportion of S1 and S2 smolts. The data are explained in the following table.

Size (g)	Price*	S1 %	S1 $	S2 %	S2 $
40 - 60	$ 3.75	35	1.31	0	0.00
61 - 75	$ 4.00	45	1.80	0	0.00
76 -100	$ 4.30	15	0.65	0	0.00
101-125	$ 4.65	5	0.23	50	2.33
> 125	$ 5.10	0	0.00	50	2.55
		65	3.99	35	4.88
Weighted Average Price			$ 4.30 / smolt		

The rationale applied to forecast productivity, hydraulic loading rate, and effluent treatment requirements are explained herein, and presented in Exhibit 6.5. The use of external rectangular basins has been deemed most appropriate for smolt production facilities. The hypothetical farm will require 2 sedimentation basins measuring 15 m wide by 20 m long and 1.5 m total depth (water depth will equal 1.22 m). In Exhibit 6.6, a dollar figure has been affixed to each component of effluent treatment. These have been broken down into fixed (capital) costs and variable (operating) costs to facilitate the analysis. A 10 year straight-line depreciation schedule has been applied on capital expenditures to derive an annual expense.

For the hypothetical smolt production operation, gross revenue has been projected at $1,505,000; i.e. 350,000 smolts @ $4.30 each. All variable and fixed costs have been allocated based upon the expenses allocated to each account, as defined during discussions with industry managers. Without effluent treatment, earnings before interest and tax (EBIT) are projected at 45.32% of revenues. Variable and fixed costs account for 29.5% and 25.2% of total costs, respectively (Exhibit 6.7).

As expected, incorporation of effluent treatment causes the bottom line to worsen. From a cost perspective, effluent treatment accounts for approximately 1.98% of total production costs. Comparatively, UMA Engineering (1988) estimates effluent treatment costs between 5% and 10% of total production costs in conventional trout culture operations. Furthermore, the UMA study presents data which suggest an increase in production costs ranging from $0.07 to $1.74 per kilogram of fish produced. This analysis indicates that, on a per smolt basis, effluent treatment will increase total production costs by $0.05. Total production costs increase from approximately $2.35/smolt to $2.40/smolt. Consequently, profit margins decline by 1.1% (Exhibit 6.7).

Based upon these calculations, it is evident that proper design, construction, and maintenance of effluent treatment facilities does not appear to impose a formidable financial burden on New Brunswick smolt production operations.

Exhibit 6.5:
Rationale for economic analysis of effluent treatment operations in intensive Atlantic Salmon smolt production.

PRODUCTIVITY	
Annual Production (# smolts)	350,000
Hydraulic Flow Rate (Lps)	370.5
EFFLUENT TREATMENT	
Design	External Rectangular
No. of Units	2
Hydr. Load/Unit (m^3/d)	16,006
Design Vo ($m^3/m^2/d$)	86.4
Unit Dimensions (m)	15x20x1.5[1]
Volume (m^3)	450

[1] Additional length has been added to compensate for turbulence and inlet & outlet structures.

Exhibit 6.6:
Annual capital and operating expenses for effluent treatment facilities at intensive Atlantic Salmon smolt production operations in New Brunswick.

CAPITAL COSTS		
SETTLING BASINS		
Design & Preparation		4,500
Construction @ $23/$m^3$		20,700
TOTAL CAPITAL EXPENSE	$	25,200
Annual Fixed Expense[1]	$	2,520
OPERATING COSTS		
POND CLEANING EXPENSE[2]		
2 Ponds, Twice annually per pond @ $9/$m^2$		10,800
LABORATORY ANALYSES		
4-TP, 4-TSS + delivery, 2 times/mo @ $136/mo		3,264
TOTAL OPERATING EXPENSE	$	14,064
TOTAL ANNUAL EXPENSE	$	16,584

[1] 10 yr. depreciation schedule.
[2] Based on actual data for pond cleaning and manure disposal.

CANADIAN AQUACULTURE SYSTEMS

Exhibit 6.7:
Economic projections reflecting the cost of effluent treatment in a hypothetical New Brunswick Atlantic Salmon smolt production operation.

INDUSTRY AVERAGE COST STRUCTURE - NO EFFLUENT TREATMENT

Production (smolts)		350,000		
Farm Gate Price ($/smolt)		4.30		
	% Revenue	$	% Costs	$/smolt
REVENUE	100.00	1,505,000		4.30
EXPENSES				
Variable Costs				
Feed	2.57	38,678	4.70	0.11
Eggs/Fingerlings	8.86	133,315	16.20	0.38
Chemicals/Drugs	1.04	15 636	1.90	0.04
General Expenses	3.88	58,428	7.10	0.17
Labour & Benefits	13.12	197,504	24.00	0.56
Effluent Treatment	0.00	0	0.00	0.00
Total Var. Costs	29.47	443,561	53.90	1.27
Contribution Margin / %	70.53	1,061,439		3.03
Fixed Costs				
Insurance	2.35	35,386	4.30	0.10
Repairs & Maint.	4.59	69,126	8.40	0.20
Utilities	11.10	167,056	20.30	0.48
Depreciation	7.16	197,804	13.10	0.31
Effluent Treatment	0.00	0	0.00	0.00
Total Fixed Costs	25.21	379,372	46.10	1.08
Total Costs	54.68	822,933	100.00	2.35
EBIT* / % Profit Margin	45.32	682,067		1.95

* Earnings Before Interest & Tax

INDUSTRY AVERAGE COST STRUCTURE - WITH EFFLUENT TREATMENT

Production (smolts)		350,000		
Farm Gate Price ($/kg)		4.30		
	% Revenue	$	% Costs	$/smolt
REVENUE	100.00	1,505,000		4.30
EXPENSES				
Variable Costs				
Feed	2.57	38,678	4.61	0.11
Eggs/Fingerlings	8.86	133,315	15.88	0.38
Chemicals/Drugs	1.04	15,636	1.86	0.04
General Expenses	3.88	58,428	6.96	0.17
Labour	13.12	197,504	23.53	0.56
Effluent Treatment	0.93	14,064	1.68	0.04
Total Var. Costs	30.41	457,625	54.51	1.31
Contribution Margin / %	69.59	1,047,375		2.99
Fixed Costs				
Insurance	2.35	35,386	4.22	0.10
Repairs & Maint.	4.59	69,126	8.23	0.20
Utilities	11.10	167,056	19.90	0.48
Depreciation	7.16	107,804	12.84	0.31
Effluent Treatment	0.17	2,520	0.30	0.01
Total Fixed Costs	25.37	381,892	45.49	1.09
Total Costs	55.78	839,517	100.00	2.40
EBIT* / % Profit Margin	44.22	665,483		1.90
EFFLUENT TREATMENT COST	1.10	16,584	1.98	0.05

7.0 EFFLUENT DISCHARGE GUIDELINES

Historically, the Department of the Environment in the Province of New Brunswick has reviewed Ontario guidelines for fish farm effluent as established by the Ontario Ministry of the Environment. A brief review of the O.M.O.E. Interim Guidelines is presented below, and includes comments concerning contentious aspects of these proposed regulations.

The Ontario Ministry of the Environment has established guidelines for the design, operation, and management of fish culture operations within provincial boundaries. Within the context of returning process water to receiving streams, these guidelines dictate that fish farmers must:

1) treat all process water, to a level of cleanliness as stated by the Ministry, prior to discharge;

2) provide for appropriate storage and disposal of collected fish manure;

3) collect and submit regular (monthly) samples of influent and effluent water for TSS and TP analysis;

4) maintain a log of daily operations at the farm; and,

5) report the findings of the water quality analyses and the data log to the Ministry on a monthly and annual basis.

The Ministry has taken the position that efficient and effective solids management is to be the focus of these guidelines. By reducing the concentration of total suspended solids in fish farm effluent, concentrations of other pollutants (namely total phosphorus, BOD, TKN) are also reduced. Moreover, solids management is perhaps the only aspect of effluent quality control which is realistically achievable in intensive salmonid aquaculture.

Current guidelines indicate that treatment facilities at fish culture operations be designed, constructed, and operated with the intention of routinely producing an effluent stream having a maximum concentration of 5 mg TSS/L above the background level of TSS in the source water. This criterion applies to both surface and ground water sources. A maximum effluent phosphorus concentration of 0.05 mg/L has been established for design purposes; however, at sites using a surface water supply where background concentrations of TP are greater than 0.05 mg/L, design criteria require that no increase over background levels be incurred.

The operator(s) of a fish culture facility will be considered to be in non-compliance with Ministry guidelines on any occasion when the concentration of TSS in the final farm discharge is observed to be greater than 10 mg/L above the concentration of TSS in the source water. Similarly, at no time can the concentration of TP in the final farm effluent exceed 0.10 mg TP/L. Notwithstanding this, at sites using surface waters where the source water concentration of TP exceeds 0.10 mg/L, farm effluent concentrations of TP cannot exceed background levels.

These phosphorus discharge criteria may be severely limiting to future and existing fish culture operations. The requirement that effluent concentrations of TP not exceed source water concentrations implies that removal of total phosphorus from discharged culture water must be 100% efficient at those culture sites where the source water already contains total phosphorus concentrations greater than 0.05 mg/L. Since this is impossible, such fish culture operations would be in non-compliance. The only recourse for aquaculturists remains to undertake a study to demonstrate the assimilative capacity of the receiving water course and the impact of the fish culture operation. This issue presents serious ramifications (and expense) to both the enforcing government agency and the private sector and, therefore, requires a co-operative effort to be resolved. Undoubtedly, the assimilative capacity of the receiving water body must be the ultimate benchmark for the establishment of discharge guidelines in sensitive watersheds.

The requirement for routine sampling of influent and effluent process water raises concern. The purpose of collecting water quality samples is to compile data on fish culture operations and to monitor effluent quality. Since the responsibility of collecting the samples lies with the aquaculturist, considerable variability will be introduced into the data. Moreover, the door remains wide open for farmers to misdirect the Department by submitting uncharacteristic effluent water samples. For instance, fish may not be fed during the period prior to sampling (this has been experienced by CAS during field monitoring programs), or influent water may be mixed with effluent water in the sample to dilute the concentration of TSS and TP. Consequently, to be effective, a DOE-directed or an industry-government co-operative monitoring program will be required. This may entail a shared-cost approach and the education of aquaculturists with respect to proper sampling procedures.

8.0 PROJECT SUMMARY

8.1 Intensive Salmonid Culture Operations

8.1.1 In the New Brunswick smolt industry, circular tanks are used almost exclusively. In comparison, Ontario trout producers use three principal commercial fish culture facility designs. All of these culture facilities have been found to produce more or less the same amount of fish per unit water flow through the system.

8.1.2 Generally, standard raceways and circular tanks are similar with respect to production parameters and effluent quality. Oval raceways are distinctively different, producing poorer quality effluents; particularly, TP, DP, TKN, NH_3, and NO_2 have been observed to be discharged in greater concentrations. New Brunswick smolt production operations and standard raceway facilities were found to produce the highest quality effluent among the groups studied.

8.1.3 Cumulative design curves of sedimentation behaviour differ on a group basis. New Brunswick smolt operations display solids settling behaviour which is much slower than the solids settling rate observed in trout production. Interestingly, the one smolt facility which uses moist feeds displays settling rates which are highly similar to Ontario results. In Ontario trout production operations, suspended particulate matter from oval raceway production facilities displays slower settling rates than particles from standard raceway and circular tank production facilities. The latter two groups are not statistically different.

8.1.4 Settling behaviour is discrete in all salmonid culture facilities.

8.1.5 In all groups, production intensity is positively correlated with enhanced concentrations of dissolved nutrients (TP, DP, NH_3, TKN) in the discharged effluent.

8.1.6 Feed-related factors (feed brand, feed type, feeding method) appear to be subordinate to facilities design and culture practices with respect to pollution impact.

8.2 Effluent Treatment Design

8.2.1 Overflow rate must be the basis for effective treatment facility design. Specific design parameters are detailed in Sections 6.2 through 6.4. Settling facilities for New Brunswick smolt production operations should be designed using an overflow rate $\leq 86\ m^3/m^2/d$ (0.100 cm/s); or, for every Imperial gallon of water flowing through the treatment facility, 0.82 square feet of surface area should be provided. Inlet structures must be designed to minimize turbulence and mixing at the entry to the settling zone. This is generally best achieved using a submerged wide-top weir which extends across the full width of the basin. Outlets should also extend across the entire width of the settling basin to minimize the outlet weir rate and reduce the effect of particle entrainment in the

CANADIAN AQUACULTURE SYSTEMS

discharge current. Moreover, the length of the functional settling basin should be extended to compensate for entrainment; the appropriate length of this extension being governed by the weir rate. Generally, one to two times the basin depth is an appropriate length increment.

8.2.2 Due to the variability in effluent quality which is inherent in commercial salmonid culture due to seasonal changes in productivity, enforcement of effluent discharge criteria (i.e. maximum concentrations) may not be an appropriate means of industry regulation. Rather, aquaculture facilities should be required to design effluent treatment facilities to achieve prescribed effluent quality targets (i.e. design the treatment facility with the intention of achieving 50% solids removal; see Exhibit 6.4). Routine monitoring will identify the level of compliance with this design mandate and will enable estimation of the cumulative mass load of pollutants to the receiving stream. Such monitoring will provide sufficient data to determine whether treatment processes are adequate for the protection of the downstream environment.

8.2.3 In all cases, the required level of treatment efficiency is more appropriately governed by the effluent concentration of total phosphorus since solids criteria are generally easily attained, even at relatively high overflow rates. In many cases (especially in trout culture), phosphorus criteria will be difficult to meet on a continuous basis. In New Brunswick, the relatively low concentrations of TSS and TP in the production effluent serve to reduce the total settling area required to achieve acceptable effluent quality.

8.2.4 Generally, the use of several smaller treatment units, each designed to clarify a portion of the total system flow, is more appropriate than having one large treatment unit to treat the entire system flow. Moreover, multiple units facilitate cleaning of settling basins by allowing individual basins to be taken off-line for solids removal while process effluent can still be treated in parallel basins.

8.2.5 For maximum effectiveness, the design of effluent treatment operations should be conducted or approved by qualified personnel having an understanding of aquaculture operations and the related effluent characteristics and constraints.

8.3 Management Strategies

8.3.1 The development and commercialization of low-phosphorus feeds is required to facilitate the reduction of phosphorus from aquaculture operations. Many commercial feeds currently contain excess dietary phosphorus.

8.3.2 At the farm level, improved feed handling and storage, and feed screening to minimize the introduction of "fines" to the water column, will also reduce the pollution impact of commercial aquaculture. As well, properly managed feed programs can reduce feed waste and pollution by providing feeds of optimum pellet size to the fish.

8.3.3 Fish culture facilities should be designed to maximize fish production and promote the removal of solid wastes from the culture medium. To this end, shallow tanks (≤100 cm) are recommended. Moreover, standard raceway and/or circular tank facilities are recommended.

8.3.4 Vacuuming and/or drain-down of settled manure from the bottom of clarifiers remain the most effective methods for waste removal. Clarifiers must be routinely cleaned to remove settled solids and reduce the potential for solubilization of particulate nutrients.

8.3.5 Due to the highly liquid state of settled fish manure and its low-grade fertilizer properties, application of settled manure on agricultural land remains the most appropriate method for disposal of solid wastes from fish culture.

8.3.6 Assuming that treatment facilities are retrofitted into existing fish culture operations, production costs can be expected to increase by approximately $0.05 per smolt produced.

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APPENDIX I

Field Survey Questionnaire

CANADIAN AQUACULTURE SYSTEMS

AQUACULTURE WASTEWATER TREATMENT
DATA SHEET

Farm No: _____ Date: _____

Fish Farm: _____ Operator: _____

Address: _____ Species: _____

_____

OPERATIONS:

Annual Prod'n: Smolts (#) _____

Feed Brand: [] Corey's [] Connors [] Other: _____

[] Floating [] Sinking

Water Source: [] Well(s) [] Spring(s) [] Surface

Volume (IGPM\LPM): _____ _____ _____

Water Flow: [] Pumped [] Gravity

SAMPLED UNIT:

[] Tanks Prod'n Area (ft\m): _____ Dia. _____ Deep

[] Raceways Prod'n Area (ft\m): _____ L _____ W _____ D

Carrying Capacity in unit (lbs\kg\# fish): _____

Approximate Size of Fish: (cm\in\lbs\g): _____

Feed Method: [] Demand [] Hand [] Automatic [] Other

Water Supply: Q (IGPM\LPM) _____ [] Flow-Thru

[] Re-use: _____% Temp (C\F): _____

EFFLUENT TREATMENT:

Method: [] In-Raceway Settling [] Ext. Settling [] Other

Dimensions: _____

Hydr. Load Rate: _____

Flow Pattern (IN/OUT): _____

Comments: _____

_____

SAMPLE LOCATIONS:

Sample 1: _____ Sample 2: _____

Sample 3: _____ Sample 4: _____

APPENDIX II
Water Quality Data from Participating Fish Farms

FARM	GROUP	INFLUENT (SOURCE)			PRODUCTION EFFLUENT			NET PROD'N EFFLUENT			FARM EFFLUENT			NET FARM EFFLUENT		
		[TSS]	[TP]	[DP]	[TSS]	[TP]	[DP]	[TSS]	[TP]	[DP]	[TSS]	[TP]	[DP]	[TSS]	[TP]	[DP]
26	1	2.31	0.015	0.066	6.26	0.046	0.022	3.95	0.031	-0.044	3.64	0.069	0.038	1.33	0.054	-0.028
1	1	NA	0.009	0.002	NA	0.126	0.074	NA	0.117	0.072	NA	0.137	0.080	NA	0.128	0.078
21	1	0.00	0.003	0.003	6.05	0.390	0.018	6.05	0.387	0.015	4.19	0.160	0.089	4.19	0.157	0.086
3	1	23.27	0.016	0.010	30.07	0.062	0.013	6.80	0.046	0.003	36.75	0.054	0.014	13.48	0.038	0.004
55	1	2.81	0.008	0.001	15.41	0.170	0.001	12.60	0.162	0.000	7.01	0.085	0.001	4.20	0.077	0.000
76	1	0.00	0.010	0.009	4.45	0.041	0.020	4.45	0.031	0.011	2.38	0.004	0.003	2.38	-0.006	-0.006
74B	1	2.47	0.008	0.003	4.49	0.055	0.009	2.02	0.047	0.006	4.49	0.055	0.009	2.02	0.047	0.006
43	1	9.03	0.051	0.009	13.43	0.305	0.063	4.40	0.254	0.054	14.85	0.210	0.063	5.82	0.159	0.054
8	1	2.78	0.005	0.005	7.29	0.028	0.010	4.51	0.023	0.005	8.03	0.028	0.016	5.25	0.023	0.011
66B	1	3.30	0.008	0.004	4.00	0.015	0.009	0.70	0.007	0.005	4.00	0.015	0.009	0.70	0.007	0.005
50	1	0.44	NA	NA	5.53	0.154	0.090	5.09	NA	NA	4.48	0.093	0.063	4.04	NA	NA
62	1	0.99	0.004	0.002	20.19	0.125	0.046	19.20	0.121	0.044	9.75	0.048	0.032	8.76	0.044	0.030
35	1	2.30	0.026	0.018	6.59	0.108	0.038	4.29	0.082	0.020	28.97	0.235	0.067	26.67	0.209	0.049
73	1	5.13	0.009	0.035	4.35	0.028	0.002	-0.78	0.019	-0.033	4.35	0.028	0.022	-0.78	0.019	-0.013
59	1	0.00	0.009	0.001	1.71	0.021	0.001	1.71	0.012	0.000	8.51	0.050	0.026	8.51	0.041	0.025
58	1	1.94	0.006	0.001	9.35	0.260	0.138	7.41	0.254	0.137	6.69	0.187	0.119	4.75	0.181	0.118
51	1	0.00	0.007	0.001	0.64	0.053	0.021	0.64	0.046	0.020	28.04	0.026	0.001	28.04	0.019	0.000
23	1	17.94	0.040	0.008	18.18	0.112	0.020	0.24	0.072	0.012	11.21	0.043	0.008	-6.73	0.003	0.000
79	1	7.51	0.014	0.001	8.56	0.124	0.013	1.05	0.110	0.012	7.08	0.040	0.015	-0.43	0.026	0.014
74A	1	1.23	0.004	0.001	3.76	0.012	0.001	2.53	0.008	0.000	3.02	0.010	0.002	1.79	0.006	0.001
77	1	0.00	0.049	0.032	4.56	0.086	0.050	4.56	0.037	0.018	7.75	0.029	0.004	7.75	-0.020	-0.028
25	1	0.00	0.003	0.002	24.00	0.115	0.015	24.00	0.112	0.013	3.42	0.129	0.079	3.42	0.126	0.077
7	1	6.02	0.023	0.009	5.38	0.130	0.012	-0.64	0.107	0.003	4.19	0.073	0.028	-1.83	0.050	0.019
66A	1	2.13	0.011	0.002	17.84	0.056	0.009	15.71	0.045	0.007	4.90	0.022	0.009	2.77	0.011	0.007
78	1	4.81	0.005	0.003	6.92	0.046	0.024	2.11	0.041	0.021	2.03	0.022	0.001	-2.78	0.017	-0.002
40	1	0.00	0.007	0.001	NA	0.162	0.043	NA	0.155	0.042	22.89	0.068	0.028	22.89	0.061	0.027
5	2	0.00	0.001	0.001	49.93	1.110	0.187	49.93	1.109	0.186	3.18	0.450	0.300	3.18	0.449	0.299
4	2	18.72	0.007	0.001	22.49	0.057	0.012	3.77	0.050	0.011	22.71	0.143	0.101	3.99	0.136	0.100
19	2	10.92	0.003	0.001	27.58	0.775	0.145	16.66	0.772	0.144	9.31	0.087	0.041	-1.61	0.084	0.040
49	2	12.14	0.014	0.011	10.42	0.270	0.144	-1.72	0.256	0.133	9.47	0.298	0.184	-2.67	0.284	0.173
15	2	4.49	0.008	0.006	5.34	0.255	0.179	0.85	0.247	0.173	1.67	0.390	0.176	-2.82	0.382	0.170
24	2	2.02	0.003	0.002	3.64	0.046	0.036	1.62	0.043	0.034	0.00	0.037	0.024	-2.02	0.034	0.022
14	2	0.14	0.013	0.004	6.27	0.180	0.082	6.13	0.167	0.078	0.00	0.160	0.085	-0.14	0.147	0.081
2	2	0.26	0.004	0.002	4.02	0.324	0.128	3.76	0.320	0.126	4.11	0.108	0.066	3.85	0.104	0.064
6	2	0.00	0.045	0.023	7.17	1.700	0.350	7.17	1.655	0.327	0.00	0.525	0.430	0.00	0.480	0.407
56	2	0.18	0.007	0.002	12.48	0.160	0.073	12.30	0.153	0.071	4.60	0.268	0.124	4.42	0.261	0.122
47	2	6.28	0.030	0.021	11.66	0.300	0.124	5.38	0.270	0.103	8.13	0.158	0.114	1.85	0.128	0.093

CANADIAN AQUACULTURE SYSTEMS

APPENDIX II (cont'd)
Water Quality Data from Participating Fish Farms

FARM	GROUP	INFLUENT (SOURCE)			PRODUCTION EFFLUENT			NET PROD'N EFFLUENT			FARM EFFLUENT			NET FARM EFFLUENT		
		[TSS]	[TP]	[DP]	[TSS]	[TP]	[DP]	[TSS]	[TP]	[DP]	[TSS]	[TP]	[DP]	[TSS]	[TP]	[DP]
27A	3	2.58	0.003	0.001	17.64	0.244	0.031	15.06	0.241	0.030	4.12	0.305	0.265	1.54	0.302	0.264
18	3	1.79	0.002	0.001	13.04	0.096	0.020	11.25	0.094	0.019	11.71	0.106	0.026	9.92	0.104	0.025
52	3	0.00	0.053	0.001	28.44	0.225	0.001	28.44	0.172	0.000	13.07	0.186	0.001	13.07	0.133	0.000
31	3	2.49	0.006	0.003	6.28	0.105	0.063	3.79	0.099	0.060	2.70	0.044	0.041	0.21	0.038	0.038
45	3	0.21	0.009	0.004	4.72	0.115	0.058	4.51	0.106	0.054	3.27	0.148	0.099	3.06	0.139	0.095
28	3	2.44	0.011	0.004	3.33	0.010	0.002	0.89	-0.001	-0.002	13.44	0.084	0.001	11.00	0.073	-0.003
16	3	1.72	0.005	0.003	6.49	0.160	0.002	4.77	0.155	-0.001	6.21	0.120	0.020	4.49	0.115	0.017
20	3	0.64	0.003	0.002	32.67	0.184	0.066	32.03	0.181	0.064	0.36	0.077	0.049	-0.28	0.074	0.047
12	3	0.00	0.046	0.014	19.05	0.186	0.076	19.05	0.140	0.062	5.08	0.155	0.081	5.08	0.109	0.067
29	3	3.47	0.003	0.001	9.13	0.177	0.045	5.66	0.174	0.044	2.77	0.139	0.083	-0.70	0.136	0.082
34	3	3.49	0.005	0.003	34.09	0.725	0.098	30.60	0.720	0.095	3.99	0.106	0.047	0.50	0.101	0.044
22	3	1.61	0.002	0.002	11.72	0.175	0.046	10.11	0.173	0.044	4.18	0.147	0.083	2.57	0.145	0.081
10	3	0.00	0.030	0.005	13.54	0.064	0.005	13.54	0.034	0.000	9.15	0.058	0.026	9.15	0.028	0.021
83	4	0.00	0.010	0.040	3.20	0.135	0.150	3.20	0.125	0.110	2.40	0.084	0.150	2.40	0.074	0.110
84	4	0.00	0.110	0.100	9.80	0.406	0.150	9.80	0.296	0.050	1.20	0.197	0.150	1.20	0.087	0.050
85	4	1.10	0.023	0.020	1.40	0.046	0.045	0.30	0.023	0.025	1.00	0.048	0.090	-0.10	0.025	0.070
86	4	0.71	0.004	0.060	2.25	0.119	0.105	1.54	0.115	0.045	2.20	0.081	0.110	1.49	0.077	0.050
87	4	0.00	0.010	0.070	0.06	0.028	0.050	0.06	0.018	-0.020	0.00	0.021	0.030	0.00	0.011	-0.040
88	4	NA	0.012	0.020	2.38	0.072	0.040	NA	0.060	0.020	1.20	0.110	0.045	NA	0.098	0.025
89	4	NA	0.026	0.040	0.69	0.101	0.065	NA	0.075	0.025	0.38	0.065	0.030	NA	0.039	-0.010
90	4	0.63	0.042	0.010	1.05	0.108	0.053	0.42	0.066	0.043	1.88	0.108	0.060	1.25	0.066	0.050
91	4	0.38	0.006	0.010	0.54	0.048	0.033	0.16	0.042	0.023	0.25	0.055	0.040	-0.13	0.049	0.030
92	4	0.38	0.006	0.010	1.69	0.039	0.020	1.31	0.033	0.010	NA	NA	NA	NA	NA	NA
93	4	0.75	0.020	0.010	3.63	0.232	0.115	2.88	0.212	0.105	1.63	0.209	0.100	0.88	0.189	0.090
MEAN	1	Standard Raceways			8.81	0.109	0.029	5.10	0.089	0.017	9.33	0.074	0.032	5.62	0.057	0.021
MEAN	2	Oval Raceways			14.64	0.471	0.133	9.62	0.458	0.126	5.74	0.239	0.150	0.73	0.226	0.143
MEAN	3	Ont. Circular Tanks			15.40	0.190	0.039	13.82	0.176	0.036	6.16	0.129	0.063	4.59	0.115	0.060
MEAN	4	N.B. Circular Tanks			2.43	0.121	0.075	1.79	0.097	0.040	1.10	0.089	0.073	0.64	0.065	0.039

APPENDIX III

Spearman's Correlation Matrices for Participating Fish Farms

CANADIAN AQUACULTURE SYSTEMS

SPEARMAN CORRELATION ANALYSIS - GROUP A (STANDARD RACEWAYS)

Spearman Correlation Coefficients / Prob > |R| under Ho: Rho=0 / N = 21

	m1	m2	m3	mCDC	INTPT	r2	INTEN	PROD	AREA	DEPTH	CROP	DENS	FLOW	REUSE	TEMP	FWI	NH3	TKN	NO2	NO3	TP	DP	TSS	SIZE	HRT
m1	1.00000 0.0	0.73814 0.0001	0.81092 0.0001	-0.56122 0.0081	0.23319 0.3090	-0.45289 0.0392	-0.09224 0.6909	-0.14300 0.5363	0.01104 0.9621	-0.25779 0.2592	0.02793 0.9043	0.03638 0.8756	0.07382 0.7505	0.29552 0.1934	-0.06780 0.7703	-0.06236 0.7883	-0.22605 0.3245	-0.21630 0.3463	-0.51491 0.0169	-0.04501 0.8464	-0.32304 0.1532	-0.16591 0.4723	-0.10266 0.6579	-0.27705 0.2240	-0.02079 0.9287
m2	0.73814 0.0001	1.00000 0.0	0.88304 0.0001	-0.69308 0.0005	0.14875 0.5199	-0.25081 0.2728	-0.02468 0.9154	0.13065 0.5724	0.11043 0.6337	-0.00802 0.9725	0.16499 0.4748	0.21306 0.3538	0.23642 0.3022	-0.14776 0.5227	-0.06486 0.7800	-0.05326 0.8186	0.22215 0.3331	0.03573 0.8778	-0.44944 0.0410	-0.11461 0.6208	-0.29119 0.2003	0.01561 0.9464	-0.09422 0.6846	-0.35300 0.1165	-0.11043 0.6337
m3	0.81092 0.0001	0.88304 0.0001	1.00000 0.0	-0.57356 0.0066	0.32673 0.1483	-0.27680 0.2245	0.06496 0.7797	0.02665 0.9087	0.10913 0.6377	-0.12238 0.5972	0.12601 0.5862	0.24034 0.2940	0.11545 0.6183	-0.03694 0.8737	0.00619 0.9787	0.04547 0.8448	0.09224 0.6909	0.02014 0.9310	-0.32963 0.1445	-0.07029 0.7621	-0.22684 0.3227	0.10540 0.6493	-0.00715 0.9755	-0.29889 0.1881	0.08055 0.7285
mCDC	-0.56122 0.0081	-0.69308 0.0005	-0.57356 0.0066	1.00000 0.0	-0.01948 0.9332	0.45794 0.0368	-0.06104 0.7927	0.14555 0.5290	0.18961 0.4104	0.32155 0.1552	0.12338 0.5942	-0.19740 0.3911	0.14044 0.5437	0.03693 0.8737	0.23982 0.2951	-0.03377 0.8845	-0.28571 0.2093	0.19740 0.3911	0.33116 0.1425	0.20422 0.3746	0.08902 0.7012	-0.10276 0.6576	-0.13576 0.5574	0.29586 0.1929	0.14805 0.5219
INTPT	0.23319 0.3090	0.14875 0.5199	0.32673 0.1483	-0.01948 0.9332	1.00000 0.0	0.30399 0.1803	0.22987 0.3161	-0.00715 0.9755	0.34545 0.1251	0.35899 0.1100	0.13636 0.5556	-0.13247 0.5670	0.04226 0.8557	0.25849 0.2579	-0.01629 0.9441	0.27273 0.2317	-0.09481 0.6827	-0.06364 0.7841	0.02814 0.9036	0.27829 0.2219	0.12476 0.5900	0.27902 0.2206	0.11302 0.6257	-0.21766 0.3432	0.38831 0.0819
r2	-0.45289 0.0392	-0.25081 0.2728	-0.27680 0.2245	0.45794 0.0368	0.30399 0.1803	1.00000 0.0	0.19422 0.3989	-0.03640 0.8755	0.06106 0.7926	0.36044 0.1085	0.05651 0.8078	0.06301 0.7861	0.00715 0.9754	-0.22164 0.3343	-0.15906 0.4910	0.19032 0.4086	-0.09094 0.6950	0.09484 0.6826	0.15123 0.5129	0.34763 0.1226	0.11147 0.6305	0.10215 0.6595	-0.23847 0.2979	-0.17503 0.4479	0.18772 0.4152
INTEN	-0.09224 0.6909	-0.02468 0.9154	0.06496 0.7797	-0.06104 0.7927	0.22987 0.3161	0.19422 0.3989	1.00000 0.0	0.03249 0.8888	0.09221 0.6910	0.24133 0.2919	0.32208 0.1545	0.50130 0.0205	-0.39792 0.0740	-0.11078 0.6326	-0.32193 0.1547	0.98701 0.0001	0.11948 0.6060	0.46234 0.0348	0.30826 0.1740	0.23260 0.3103	0.37167 0.0971	0.58407 0.0054	0.05521 0.8121	0.36234 0.1065	0.63247 0.0021
PROD	-0.14300 0.5363	0.13065 0.5724	0.02665 0.9087	0.14555 0.5290	-0.00715 0.9755	-0.03640 0.8755	0.03249 0.8888	1.00000 0.0	0.54776 0.0102	0.48130 0.0272	0.72775 0.0002	0.22937 0.3172	0.65517 0.0013	-0.24018 0.2943	0.09064 0.6960	0.01884 0.9354	0.05198 0.8229	0.17154 0.4572	0.09169 0.6926	-0.10356 0.6551	-0.08745 0.7062	-0.03319 0.8864	-0.28502 0.2105	0.06912 0.7659	-0.08967 0.6991
AREA	0.01104 0.9621	0.11043 0.6337	0.10913 0.6377	0.18961 0.4104	0.34545 0.1251	0.06106 0.7926	0.09221 0.6910	0.54776 0.0102	1.00000 0.0	0.71062 0.0003	0.83117 0.0001	-0.21558 0.3480	0.73537 0.0001	-0.18464 0.4230	0.36494 0.1038	0.07273 0.7541	-0.08831 0.7035	0.25325 0.2680	0.05039 0.8283	-0.00969 0.9667	0.07602 0.7433	0.11057 0.6333	0.08509 0.7138	0.17856 0.4387	0.32727 0.1476
DEPTH	-0.25779 0.2592	-0.00802 0.9725	-0.12238 0.5972	0.32155 0.1552	0.35899 0.1100	0.36044 0.1085	0.24133 0.2919	0.48130 0.0272	0.71062 0.0003	1.00000 0.0	0.60567 0.0036	-0.21259 0.3549	0.46488 0.0337	-0.01901 0.9348	0.11372 0.6236	0.24935 0.2757	0.09493 0.6823	0.39576 0.0758	0.30758 0.1750	0.26654 0.2428	0.09399 0.6853	0.24440 0.2857	-0.07088 0.7601	0.07212 0.7560	0.37169 0.0971
CROP	0.02793 0.9043	0.16499 0.4748	0.12601 0.5862	0.12338 0.5942	0.13636 0.5556	0.05651 0.8078	0.32208 0.1545	0.72775 0.0002	0.83117 0.0001	0.60567 0.0036	1.00000 0.0	0.26494 0.2458	0.69245 0.0005	-0.29542 0.1936	0.05279 0.8202	0.28831 0.2050	-0.08052 0.7285	0.37143 0.0974	0.11650 0.6150	0.04569 0.8441	0.12671 0.5842	0.19317 0.4015	-0.10588 0.6478	0.18508 0.4219	0.19351 0.4007
DENS	0.03638 0.8756	0.21306 0.3538	0.24034 0.2940	-0.19740 0.3911	-0.13247 0.5670	0.06301 0.7861	0.50130 0.0205	0.22937 0.3172	-0.21558 0.3480	-0.21259 0.3549	0.26494 0.2458	1.00000 0.0	-0.11964 0.6055	-0.33235 0.1410	-0.51874 0.0160	0.45195 0.0397	0.04545 0.8449	0.29740 0.1904	0.16639 0.4696	0.00623 0.9786	0.13255 0.5668	0.23089 0.3139	-0.05911 0.7991	0.07234 0.7553	-0.19091 0.4071
FLOW	0.07382 0.7505	0.23642 0.3022	0.11545 0.6183	0.14044 0.5437	0.04226 0.8557	0.00715 0.9754	-0.39792 0.0740	0.65517 0.0013	0.73537 0.0001	0.46488 0.0337	0.69245 0.0005	-0.11964 0.6055	1.00000 0.0	-0.25883 0.2573	0.32366 0.1524	-0.42458 0.0551	-0.12224 0.5976	0.08388 0.7178	-0.10944 0.6368	-0.03085 0.8944	-0.30416 0.1801	-0.22664 0.3232	-0.12228 0.5975	-0.04861 0.8342	-0.28023 0.2185
REUSE	0.29552 0.1934	-0.14776 0.5227	-0.03694 0.8737	0.03693 0.8737	0.25849 0.2579	-0.22164 0.3343	-0.11078 0.6326	-0.24018 0.2943	-0.18464 0.4230	-0.01901 0.9348	-0.29542 0.1936	-0.33235 0.1410	-0.25883 0.2573	1.00000 0.0	0.00000 1.0000	0.03693 0.8737	-0.29542 0.1936	-0.18464 0.4230	0.27914 0.2204	0.35431 0.1151	-0.11085 0.6324	0.07398 0.7500	-0.07388 0.7503	0.03706 0.8733	0.00000 1.0000
TEMP	-0.06780 0.7703	-0.06486 0.7800	0.00619 0.9787	0.23982 0.2951	-0.01629 0.9441	-0.15906 0.4910	-0.32193 0.1547	0.09064 0.6960	0.36494 0.1038	0.11372 0.6236	0.05279 0.8202	-0.51874 0.0160	0.32366 0.1524	0.00000 1.0000	1.00000 0.0	-0.31281 0.1674	-0.00130 0.9955	-0.00782 0.9732	0.07718 0.7395	-0.08406 0.7171	-0.23411 0.3071	0.00359 0.9877	-0.01434 0.9508	0.26553 0.2447	0.00782 0.9732
FWI	-0.06236 0.7883	-0.05326 0.8186	0.04547 0.8448	-0.03377 0.8845	0.27273 0.2317	0.19032 0.4086	0.98701 0.0001	0.01884 0.9354	0.07273 0.7541	0.24935 0.2757	0.28831 0.2050	0.45195 0.0397	-0.42458 0.0551	0.03693 0.8737	-0.31281 0.1674	1.00000 0.0	0.07403 0.7498	0.43636 0.0480	0.34818 0.1219	0.29975 0.1868	0.34048 0.1310	0.58667 0.0052	0.00909 0.9688	0.38449 0.0853	0.62987 0.0022
NH3	-0.22605 0.3245	0.22215 0.3331	0.09224 0.6909	-0.28571 0.2093	-0.09481 0.6827	-0.09094 0.6950	0.11948 0.6060	0.05198 0.8229	-0.08831 0.7035	0.09493 0.6823	-0.08052 0.7285	0.04545 0.8449	-0.12224 0.5976	-0.29542 0.1936	-0.00130 0.9955	0.07403 0.7498	1.00000 0.0	0.43636 0.0480	0.12697 0.5834	-0.01315 0.9549	0.39181 0.0790	0.35772 0.1114	0.29295 0.1975	-0.09384 0.6858	0.02597 0.9110
TKN	-0.21630 0.3463	0.03573 0.8778	0.02014 0.9310	0.19740 0.3911	-0.06364 0.7841	0.09484 0.6826	0.46234 0.0348	0.17154 0.4572	0.25325 0.2680	0.39576 0.0758	0.37143 0.0974	0.29740 0.1904	0.08388 0.7178	-0.18464 0.4230	-0.00782 0.9732	0.43636 0.0480	0.43636 0.0480	1.00000 0.0	0.41952 0.0583	0.16614 0.4717	0.28460 0.2112	0.44423 0.0436	0.27606 0.2258	0.41382 0.0622	0.13247 0.5670
NO2	-0.51491 0.0169	-0.44944 0.0410	-0.32963 0.1445	0.33116 0.1425	0.02814 0.9036	0.15123 0.5129	0.30826 0.1740	0.09169 0.6926	0.05039 0.8283	0.30758 0.1750	0.11650 0.6150	0.16689 0.4696	-0.10944 0.6368	0.27914 0.2204	0.07718 0.7395	0.34818 0.1219	0.12697 0.5834	0.41952 0.0583	1.00000 0.0	0.34293 0.1280	0.26327 0.2489	0.69257 0.0005	0.04779 0.8370	0.43022 0.0516	0.06545 0.7781
NO3	-0.04501 0.8464	-0.11461 0.6208	-0.07029 0.7621	0.20422 0.3746	0.27829 0.2219	0.34763 0.1226	0.23260 0.3103	-0.10356 0.6551	-0.00969 0.9667	0.26654 0.2428	0.04569 0.8441	0.00623 0.9786	-0.03085 0.8944	0.35431 0.1151	-0.08406 0.7171	0.29975 0.1868	-0.01315 0.9549	0.16614 0.4717	0.34293 0.1280	1.00000 0.0	-0.21890 0.3404	0.23749 0.2999	-0.08067 0.7281	-0.11568 0.6176	0.10869 0.6391
TP	-0.32304 0.1532	-0.29119 0.2003	-0.22684 0.3227	0.08902 0.7012	0.12476 0.5900	0.11147 0.6305	0.37167 0.0971	-0.08745 0.7062	0.07602 0.7433	0.09399 0.6853	0.12671 0.5842	0.13255 0.5663	-0.30416 0.1801	-0.11085 0.6324	-0.23411 0.3071	0.34048 0.1310	0.39181 0.0790	0.28460 0.2112	0.26327 0.2489	-0.21890 0.3404	1.00000 0.0	0.44842 0.0415	0.40786 0.0664	0.00946 0.9676	0.33788 0.1341
DP	-0.16591 0.4723	0.01561 0.9464	0.10540 0.6493	-0.10276 0.6576	0.27902 0.2206	0.10215 0.6595	0.58407 0.0054	-0.03319 0.8864	0.11057 0.6333	0.24440 0.2857	0.19317 0.4015	0.23089 0.3139	-0.22664 0.3232	0.07398 0.7500	0.00359 0.9877	0.58667 0.0052	0.35772 0.1114	0.44423 0.0436	0.69257 0.0005	0.23749 0.2999	0.44842 0.0415	1.00000 0.0	0.07742 0.7387	0.27872 0.2211	0.32976 0.1443
TSS	-0.10266 0.6579	-0.09424 0.6846	-0.00715 0.9755	-0.13576 0.5574	0.11302 0.6257	-0.23847 0.2979	0.05521 0.8121	-0.28502 0.2105	0.08509 0.7138	-0.07088 0.7601	-0.10588 0.6478	-0.05911 0.7991	-0.12228 0.5975	-0.07388 0.7503	-0.01434 0.9508	0.00909 0.9688	0.29295 0.1975	0.27606 0.2258	0.04779 0.8370	-0.08067 0.7281	0.40786 0.0664	0.07742 0.7387	1.00000 0.0	0.00945 0.9676	0.10913 0.6377
SIZE	-0.27705 0.2240	-0.35300 0.1165	-0.29889 0.1881	0.29586 0.1929	-0.21766 0.3432	-0.17503 0.4479	0.36234 0.1065	0.06912 0.7659	0.17856 0.4387	0.07212 0.7560	0.18508 0.4219	0.07234 0.7553	-0.04861 0.8342	0.03706 0.8733	0.26553 0.2447	0.38449 0.0853	-0.09384 0.6858	0.41382 0.0622	0.43022 0.0516	-0.11568 0.6176	0.00946 0.9676	0.27872 0.2211	0.00945 0.9676	1.00000 0.0	0.17139 0.4576
HRT	-0.02079 0.9287	-0.11043 0.6337	0.08055 0.7285	0.14805 0.5219	0.38831 0.0819	0.18772 0.4152	0.63247 0.0021	-0.08967 0.6991	0.32727 0.1476	0.37169 0.0971	0.19351 0.4007	-0.19091 0.4071	-0.28023 0.2185	0.00000 1.0000	0.00782 0.9732	0.62987 0.0022	0.02597 0.9110	0.13247 0.5670	0.06545 0.7781	0.10869 0.6391	0.33788 0.1341	0.32976 0.1443	0.10913 0.6377	-0.17139 0.4576	1.00000 0.0

SPEARMAN CORRELATION ANALYSIS - GROUP B (OVAL RACEWAYS)

Spearman Correlation Coefficients / Prob > |R| under Ho: Rho=0 / N = 11

	m1	m2	m3	mCDC	INTPT	r2	INTEN	PROD	AREA	DEPTH	CROP	DENS	FLOW	REUSE	TEMP	FWI	NH3	TKN	NO2	NO3	TP	DP	TSS	SIZE	HRT
m1	1.00000 0.0	0.90909 0.0001	0.37273 0.2589	-0.78182 0.0045	-0.34545 0.2981	-0.44647 0.1686	-0.16364 0.6307	0.03636 0.9155	0.29613 0.3766	-0.17808 0.6004	-0.40000 0.2229	-0.46364 0.1509	-0.38182 0.2465	-0.19771 0.5601	0.26028 0.4395	-0.45455 0.1601	-0.62727 0.0388	-0.55455 0.0767	0.02727 0.9366	0.01822 0.9576	-0.21818 0.5192	-0.48182 0.1334	-0.41818 0.2006	-0.01835 0.9573	-0.04545 0.8944
m2	0.90909 0.0001	1.00000 0.0	0.26364 0.4334	-0.67273 0.0233	-0.06364 0.8525	-0.40547 0.2160	-0.12727 0.7092	-0.11818 0.7293	0.08200 0.8106	-0.21461 0.5263	-0.41818 0.2006	-0.51818 0.1025	-0.48182 0.1334	-0.05977 0.8614	0.33334 0.3165	-0.33636 0.3118	-0.62727 0.0388	-0.51818 0.1025	0.14545 0.6696	-0.00911 0.9788	-0.12727 0.7092	-0.38182 0.2466	-0.30000 0.3701	-0.11010 0.7473	-0.08182 0.8110
m3	0.37273 0.2589	0.26364 0.4334	1.00000 0.0	-0.30000 0.3701	0.03636 0.9155	0.40547 0.2160	0.09091 0.7904	0.15455 0.6500	0.18223 0.5918	0.05936 0.8624	0.19091 0.5739	0.12727 0.7092	0.17273 0.6115	0.12415 0.7161	-0.10046 0.7688	0.13636 0.6893	-0.31818 0.3403	-0.38182 0.2466	0.13636 0.6893	0.38724 0.2393	-0.10000 0.7699	-0.07273 0.8317	-0.57273 0.0655	-0.09175 0.7685	-0.15455 0.6500
mCDC	-0.78182 0.0045	-0.67273 0.0233	-0.30000 0.3701	1.00000 0.0	0.60909 0.0467	0.45103 0.1638	0.13636 0.6893	0.12727 0.7092	-0.38269 0.2454	0.00913 0.9787	0.31818 0.3403	0.51818 0.1025	0.20909 0.5372	-0.12874 0.7060	-0.23745 0.4820	0.25455 0.4500	0.69091 0.0186	0.39091 0.2345	-0.41818 0.2006	-0.14123 0.6787	0.17273 0.6115	0.41818 0.2006	0.15455 0.6500	0.14680 0.6667	-0.15455 0.6500
INTPT	-0.34545 0.2981	-0.06364 0.8525	0.03636 0.9155	0.60909 0.0467	1.00000 0.0	0.40091 0.2217	0.40000 0.2229	0.01818 0.9577	-0.23690 0.4831	0.00000 1.0000	0.37273 0.2589	0.34545 0.2981	-0.18182 0.5926	0.00460 0.9893	0.21918 0.5173	0.50909 0.1097	0.52727 0.0956	0.39091 0.2345	-0.03636 0.9155	-0.13212 0.6986	0.33636 0.3118	0.54545 0.0827	-0.10000 0.7699	0.22937 0.4975	0.03636 0.9155
r2	-0.44647 0.1686	-0.40547 0.2160	0.40547 0.2160	0.45103 0.1638	0.40091 0.2217	1.00000 0.0	0.35535 0.2835	0.06834 0.8418	-0.42237 0.1956	-0.11899 0.7275	0.44191 0.1736	0.56492 0.0702	0.09567 0.7796	-0.05761 0.8664	-0.23341 0.4897	0.32802 0.3247	0.35991 0.2769	0.26879 0.4242	0.20501 0.5454	-0.15068 0.6583	0.45558 0.1591	0.39180 0.2334	-0.20501 0.5454	-0.23449 0.4877	-0.34624 0.2969
INTEN	-0.16364 0.6307	-0.12727 0.7092	0.09091 0.7904	0.13636 0.6893	0.40000 0.2229	0.35535 0.2835	1.00000 0.0	0.40000 0.2229	0.41002 0.2104	0.22831 0.4995	0.88182 0.0003	0.69091 0.0186	-0.08182 0.8110	-0.23450 0.4876	0.10959 0.7484	0.74545 0.0085	0.50909 0.1097	0.62727 0.0388	0.49091 0.1252	-0.39180 0.2334	0.71818 0.0128	0.77273 0.0053	-0.31818 0.3403	0.43121 0.1854	0.39091 0.2345
PROD	0.03636 0.9155	-0.11818 0.7293	0.15455 0.6500	0.12727 0.7092	0.01818 0.9577	0.06834 0.8418	0.40000 0.2229	1.00000 0.0	0.22779 0.5005	-0.28767 0.3910	0.60000 0.0510	0.60909 0.0467	0.47273 0.1420	-0.02759 0.9358	-0.51142 0.1078	0.36364 0.2716	0.32727 0.3259	0.18182 0.5926	-0.21818 0.5192	0.08656 0.8002	0.13636 0.6893	0.26364 0.4334	-0.77273 0.0053	0.01835 0.9573	0.13636 0.6893
AREA	0.29613 0.3766	0.08200 0.8106	0.18223 0.5918	-0.38269 0.2454	-0.23690 0.4831	-0.42237 0.1956	0.41002 0.2104	0.22779 0.5005	1.00000 0.0	0.59039 0.0556	0.35535 0.2835	0.12301 0.7186	-0.04556 0.8942	-0.24195 0.4735	0.27689 0.4098	0.25057 0.4574	-0.00456 0.9894	0.09112 0.7899	0.09567 0.7796	-0.02511 0.9416	-0.06834 0.8418	0.13212 0.6986	-0.20046 0.5545	0.74025 0.0092	0.67426 0.0229
DEPTH	-0.17808 0.6004	-0.21461 0.5263	0.05936 0.8624	0.00913 0.9787	0.00000 1.0000	-0.11899 0.7275	0.22831 0.4995	-0.28767 0.3910	0.59039 0.0556	1.00000 0.0	0.22831 0.4995	-0.10502 0.7586	-0.12786 0.7079	0.03002 0.9302	0.05734 0.8670	0.35160 0.2890	0.06393 0.8519	0.14155 0.6780	0.23288 0.4907	-0.20595 0.5435	0.05480 0.8729	0.33790 0.3095	0.31964 0.3380	0.51153 0.1076	0.69864 0.0168
CROP	-0.40000 0.2229	-0.41818 0.2006	0.19091 0.5739	0.31818 0.3403	0.37273 0.2589	0.44191 0.1736	0.88182 0.0003	0.60000 0.0510	0.35535 0.2835	0.22831 0.4995	1.00000 0.0	0.82727 0.0017	0.34545 0.2981	0.02299 0.9465	-0.22831 0.4995	0.87273 0.0005	0.58182 0.0604	0.60000 0.0510	0.32727 0.3259	-0.08656 0.8002	0.56364 0.0710	0.79091 0.0037	-0.38182 0.2466	0.30277 0.3655	0.36364 0.2716
DENS	-0.46364 0.1509	-0.51818 0.1025	0.12727 0.7092	0.51818 0.1025	0.34545 0.2981	0.56492 0.0702	0.69091 0.0186	0.60909 0.0467	0.12301 0.7186	-0.10502 0.7586	0.82727 0.0017	1.00000 0.0	0.36364 0.2716	-0.28508 0.3955	-0.17808 0.6004	0.53636 0.0890	0.54545 0.0827	0.40909 0.2115	-0.05455 0.8734	-0.04100 0.9047	0.30909 0.3550	0.46364 0.1509	-0.43636 0.1797	0.29359 0.3809	-0.05455 0.8734
FLOW	-0.38182 0.2466	-0.48182 0.1334	0.17273 0.6115	0.20909 0.5372	-0.18182 0.5926	0.09567 0.7796	-0.08182 0.8110	0.47273 0.1420	-0.04556 0.8942	-0.12786 0.7079	0.34545 0.2981	0.36364 0.2716	1.00000 0.0	0.55176 0.0785	-0.65297 0.0294	0.30000 0.3701	0.03636 0.9155	-0.06364 0.8525	-0.10000 0.7699	0.73349 0.0102	-0.19091 0.5739	0.06364 0.8525	-0.10909 0.7498	-0.30277 0.3655	-0.18182 0.5926
REUSE	-0.19771 0.5601	-0.05977 0.8614	0.12415 0.7161	-0.12874 0.7060	0.00460 0.9893	-0.05761 0.8664	-0.23450 0.4876	-0.02759 0.9358	-0.24195 0.4735	0.03002 0.9302	0.02299 0.9465	-0.28508 0.3955	0.55176 0.0785	1.00000 0.0	-0.43419 0.1821	0.39083 0.2346	-0.17472 0.6074	-0.03219 0.9252	0.35405 0.2854	0.58989 0.0561	-0.04138 0.9038	0.13794 0.6859	0.16093 0.6364	-0.58933 0.0564	0.10575 0.7570
TEMP	0.26028 0.4395	0.33334 0.3165	-0.10046 0.7688	-0.23745 0.4820	0.21918 0.5173	-0.23341 0.4897	0.10959 0.7484	-0.51142 0.1078	0.27689 0.4098	0.05734 0.8670	-0.22831 0.4995	-0.17808 0.6004	-0.65297 0.0294	-0.43419 0.1821	1.00000 0.0	-0.18722 0.5815	-0.02740 0.9363	0.10046 0.7688	0.07753 0.8205	-0.17163 0.6139	-0.03653 0.9151	-0.12786 0.7079	0.24658 0.4648	0.57604 0.0636	0.06393 0.8519
FWI	-0.45455 0.1601	-0.33636 0.3118	0.13636 0.6893	0.25455 0.4500	0.50909 0.1097	0.32802 0.3247	0.74545 0.0085	0.36364 0.2716	0.25057 0.4574	0.35160 0.2890	0.87273 0.0005	0.53636 0.0890	0.30000 0.3701	0.39083 0.2346	-0.18722 0.5815	1.00000 0.0	0.50000 0.1173	0.60909 0.0467	0.48182 0.1334	0.01367 0.9682	0.52727 0.0956	0.83636 0.0013	-0.18182 0.5926	0.16514 0.6275	0.52727 0.0956
NH3	-0.62727 0.0388	-0.62727 0.0388	-0.31818 0.3403	0.69091 0.0186	0.52727 0.0956	0.35991 0.2769	0.50909 0.1097	0.32727 0.3259	-0.00456 0.9894	0.06393 0.8519	0.58182 0.0604	0.54545 0.0827	0.03636 0.9155	-0.17472 0.6074	-0.02740 0.9363	0.50000 0.1173	1.00000 0.0	0.89091 0.0002	-0.08182 0.8110	-0.38724 0.2393	0.59091 0.0556	0.76364 0.0062	0.02727 0.9365	0.33946 0.3071	0.27273 0.4171
TKN	-0.55455 0.0767	-0.51818 0.1025	-0.38182 0.2466	0.39091 0.2345	0.39091 0.2345	0.26879 0.4242	0.62727 0.0388	0.18182 0.5926	0.09112 0.7899	0.14155 0.6780	0.60000 0.0510	0.40909 0.2115	-0.06364 0.8525	-0.03219 0.9252	0.10046 0.7688	0.60909 0.0467	0.89091 0.0002	1.00000 0.0	0.31818 0.3403	-0.44647 0.1686	0.75455 0.0073	0.83636 0.0013	0.16364 0.6307	0.27524 0.4127	0.43636 0.1797
NO2	0.02727 0.9366	0.14545 0.6696	0.13636 0.6893	-0.41818 0.2006	-0.03636 0.9155	0.20501 0.5454	0.49091 0.1252	-0.21818 0.5192	0.09567 0.7796	0.23288 0.4907	0.32727 0.3259	-0.05455 0.8734	-0.10000 0.7699	0.35405 0.2854	0.07763 0.8205	0.48182 0.1334	-0.08182 0.8110	0.31818 0.3403	1.00000 0.0	-0.14579 0.6689	0.63636 0.0353	0.46364 0.1509	0.17273 0.6115	-0.21102 0.5334	0.23636 0.4841
NO3	0.01822 0.9576	-0.00911 0.9788	0.38724 0.2393	-0.14123 0.6787	-0.13212 0.6986	-0.15068 0.6583	-0.39180 0.2334	0.08656 0.8002	-0.02511 0.9416	-0.20595 0.5435	-0.08656 0.8002	-0.04100 0.9047	0.73349 0.0102	0.58989 0.0561	-0.17163 0.6139	0.01367 0.9682	-0.38724 0.2393	-0.44647 0.1686	-0.14579 0.6689	1.00000 0.0	-0.56037 0.0730	-0.34624 0.2969	-0.05923 0.8627	-0.25288 0.4531	-0.31891 0.3391
TP	-0.21818 0.5192	-0.12727 0.7092	-0.10000 0.7699	0.17273 0.6115	0.33636 0.3118	0.45558 0.1591	0.71818 0.0128	0.13636 0.6893	-0.06834 0.8418	0.05480 0.8729	0.56364 0.0710	0.30909 0.3550	-0.19091 0.5739	-0.04138 0.9038	-0.03653 0.9151	0.52727 0.0956	0.59091 0.0556	0.75455 0.0073	0.63636 0.0353	-0.56037 0.0730	1.00000 0.0	0.83636 0.0013	0.01818 0.9577	-0.02752 0.9360	0.18182 0.5926
DP	-0.48182 0.1334	-0.38182 0.2466	-0.07273 0.8317	0.41818 0.2006	0.54545 0.0827	0.39180 0.2334	0.77273 0.0053	0.26364 0.4334	0.13212 0.6986	0.33790 0.3095	0.79091 0.0037	0.46364 0.1509	0.06364 0.8525	0.13794 0.6859	-0.12786 0.7079	0.83636 0.0013	0.76364 0.0062	0.83636 0.0013	0.46364 0.1509	-0.34624 0.2969	0.83636 0.0013	1.00000 0.0	0.00909 0.9788	0.21102 0.5334	0.45455 0.1601
TSS	-0.41818 0.2006	-0.30000 0.3701	-0.57273 0.0655	0.15455 0.6500	-0.10000 0.7699	-0.20501 0.5454	-0.31818 0.3403	-0.77273 0.0053	-0.20046 0.5545	0.31964 0.3380	-0.38182 0.2466	-0.43636 0.1797	-0.10909 0.7495	0.16093 0.6364	0.24658 0.4648	-0.18182 0.5926	0.02727 0.9366	0.16364 0.6307	0.17273 0.6115	-0.05923 0.8627	0.01818 0.9577	0.00909 0.9788	1.00000 0.0	0.00917 0.9786	-0.00909 0.9788
SIZE	-0.01835 0.9573	-0.11010 0.7473	-0.09175 0.7885	0.14680 0.6667	0.22937 0.4975	-0.23449 0.4877	0.43121 0.1854	0.01835 0.9573	0.74025 0.0092	0.51153 0.1076	0.30277 0.3655	0.29359 0.3809	-0.30277 0.3655	-0.58933 0.0564	0.57604 0.0636	0.16514 0.6275	0.33946 0.3071	0.27524 0.4127	-0.21102 0.5334	-0.25288 0.4531	-0.02752 0.9360	0.21102 0.5334	0.00917 0.9786	1.00000 0.0	0.47708 0.1379
HRT	-0.04545 0.8944	-0.08182 0.8110	-0.15455 0.6500	-0.15455 0.6500	0.03636 0.9155	-0.34624 0.2969	0.39091 0.2345	0.13636 0.6893	0.67426 0.0229	0.69864 0.0168	0.36364 0.2716	-0.05455 0.8734	-0.18182 0.5926	0.10575 0.7570	0.06393 0.8519	0.52727 0.0956	0.27273 0.4171	0.43636 0.1797	0.23636 0.4841	-0.31891 0.3391	0.18182 0.5926	0.45455 0.1601	-0.00909 0.9788	0.47708 0.1379	1.00000 0.0

SPEARMAN CORRELATION ANALYSIS - GROUP C (CIRCULAR TANKS)

Spearman Correlation Coefficients / Prob > |R| under Ho: Rho=0 / N = 12

	m1	m2	m3	mCDC	INTPT	r2	INTEN	PROD	AREA	DEPTH	CROP	DENS	FLOW	REUSE	TEMP	FWI	NH3	TKN	NO2	NO3	TP	DP	TSS	SIZE	HRT
m1	1.00000 0.0	0.95804 0.0001	0.60140 0.0386	-0.93706 0.0001	0.08392 0.7954	-0.18881 0.5567	0.02797 0.9312	-0.41958 0.1745	-0.28333 0.3722	-0.36364 0.2453	-0.09091 0.7787	0.16084 0.6175	-0.31918 0.3119	-0.21836 0.4954	-0.10158 0.7534	-0.01399 0.9656	-0.01399 0.9656	-0.36364 0.2453	-0.41568 0.1790	-0.16678 0.6044	0.08392 0.7954	-0.23860 0.4552	0.25874 0.4168	0.04895 0.8799	0.13986 0.6646
m2	0.95804 0.0001	1.00000 0.0	0.65035 0.0220	-0.91608 0.0001	0.04895 0.8799	-0.17483 0.5868	-0.13986 0.6646	-0.44056 0.1517	-0.25064 0.4320	-0.44755 0.1446	-0.17483 0.5868	0.07692 0.8122	-0.24825 0.4366	-0.21836 0.4954	0.03503 0.9139	-0.17483 0.5868	-0.18182 0.5717	-0.48252 0.1121	-0.50095 0.0971	-0.05076 0.8755	-0.02797 0.9312	-0.17544 0.5855	0.18881 0.5557	-0.02098 0.9484	0.05594 0.8629
m3	0.60140 0.0386	0.65035 0.0220	1.00000 0.0	-0.74825 0.0051	0.08392 0.7954	-0.07692 0.8122	0.00699 0.9828	-0.34965 0.2652	0.20705 0.5185	-0.11189 0.7292	0.27273 0.3911	0.21678 0.4986	0.20569 0.5213	0.48038 0.1139	0.00000 1.0000	0.04196 0.8970	-0.12587 0.6967	-0.03497 0.9141	-0.47964 0.1146	-0.15227 0.6366	0.41259 0.1826	0.15439 0.6319	0.37762 0.2262	0.08392 0.7954	0.04895 0.8799
mCDC	-0.93706 0.0001	-0.91608 0.0001	-0.74825 0.0051	1.00000 0.0	0.00699 0.9828	0.34965 0.2652	-0.10490 0.7456	0.58042 0.0479	0.18525 0.5643	0.27972 0.3786	0.02098 0.9484	-0.16084 0.6175	0.26953 0.3969	0.13101 0.6848	-0.05254 0.8712	-0.06294 0.8459	-0.13986 0.6646	0.16084 0.6175	0.34818 0.2674	0.19578 0.5420	-0.31469 0.3191	0.02456 0.9396	-0.41259 0.1826	-0.23776 0.4568	-0.18182 0.5717
INTPT	0.08392 0.7954	0.04895 0.8799	0.08392 0.7954	0.00699 0.9828	1.00000 0.0	0.19580 0.5419	-0.27273 0.3911	-0.11888 0.7129	0.03632 0.9108	-0.06993 0.8290	-0.06294 0.8459	-0.26573 0.4038	0.23407 0.4640	0.04367 0.8928	-0.02452 0.9397	-0.30070 0.3423	-0.27273 0.3911	-0.17483 0.5868	-0.16343 0.6118	0.26104 0.4125	-0.29371 0.3541	-0.28421 0.3706	-0.16783 0.6021	-0.02093 0.9484	-0.56643 0.0548
r2	-0.18881 0.5567	-0.17483 0.5868	-0.07692 0.8122	0.34965 0.2652	0.19580 0.5419	1.00000 0.0	-0.44755 0.1446	0.72727 0.0074	0.42136 0.1725	-0.02797 0.9312	0.00699 0.9828	-0.13986 0.6646	0.26953 0.3969	0.30570 0.3339	-0.62697 0.0291	-0.33566 0.2861	-0.56643 0.0548	-0.19580 0.5419	-0.18475 0.5654	0.12327 0.7027	-0.39161 0.2081	-0.16842 0.6008	-0.22378 0.4845	-0.72727 0.0074	-0.11189 0.7292
INTEN	0.02797 0.9312	-0.13986 0.6646	0.00699 0.9828	-0.10490 0.7456	-0.27273 0.3911	-0.44755 0.1446	1.00000 0.0	-0.00699 0.9828	-0.02906 0.9286	0.66434 0.0185	0.72028 0.0082	0.78322 0.0026	0.00709 0.9825	0.04367 0.8928	0.21366 0.5049	0.98601 0.0001	0.80420 0.0016	0.66434 0.0185	0.22738 0.4772	-0.31180 0.3238	0.77622 0.0030	0.32983 0.2951	0.48455 0.1377	0.39161 0.2081	0.37762 0.2262
PROD	-0.41958 0.1745	-0.44056 0.1517	-0.34965 0.2652	0.58042 0.0479	-0.11888 0.7129	0.72727 0.0074	-0.00699 0.9828	1.00000 0.0	0.38867 0.2118	0.14685 0.6488	0.25175 0.4299	0.23776 0.4568	0.12767 0.6925	0.30570 0.3339	-0.50788 0.0918	0.08392 0.7954	-0.23776 0.4568	-0.00699 0.9828	0.06395 0.8435	0.15953 0.6204	-0.18182 0.5717	0.12281 0.7038	-0.47552 0.1182	-0.57343 0.0513	0.28571 0.3663
AREA	-0.28333 0.3722	-0.25064 0.4320	0.20705 0.5185	-0.18525 0.5643	0.03632 0.9108	0.42136 0.1725	-0.02906 0.9286	0.38867 0.2118	1.00000 0.0	0.37051 0.2358	0.51217 0.0887	0.05449 0.8664	0.58949 0.0437	0.40832 0.1876	-0.24016 0.4521	0.03632 0.9108	0.02906 0.9286	0.33055 0.2940	0.08858 0.7843	-0.23352 0.4651	0.36687 0.2408	0.20413 0.5245	0.02543 0.9375	0.15619 0.6278	-0.07991 0.8050
DEPTH	-0.36364 0.2453	-0.44755 0.1446	-0.11189 0.7292	0.27972 0.3786	-0.06993 0.8290	-0.02797 0.9312	0.66434 0.0185	0.14685 0.6488	0.37051 0.2358	1.00000 0.0	0.69930 0.0114	0.39860 0.1993	0.36174 0.2479	0.13101 0.6848	0.22417 0.4837	0.71329 0.0092	0.49650 0.1006	0.79021 0.0022	0.42634 0.1670	-0.33355 0.2894	0.58042 0.0479	0.31579 0.3173	0.52448 0.0800	0.26573 0.4038	0.02098 0.9484
CROP	-0.09091 0.7787	-0.17483 0.5868	0.27273 0.3911	0.02098 0.9484	-0.06294 0.8459	0.00699 0.9828	0.72028 0.0082	0.25175 0.4299	0.51217 0.0887	0.69930 0.0114	1.00000 0.0	0.79720 0.0019	0.62418 0.0301	0.48038 0.1139	0.04203 0.8968	0.76923 0.0034	0.40559 0.1908	0.54545 0.0666	-0.11014 0.7333	-0.35531 0.2571	0.72727 0.0074	0.23158 0.4689	0.39860 0.1993	0.18182 0.5717	0.00699 0.9828
DENS	0.16084 0.6175	0.07692 0.8122	0.21678 0.4986	-0.16084 0.6175	-0.26573 0.4038	-0.13986 0.6646	0.78322 0.0026	0.23776 0.4568	0.05449 0.8664	0.39860 0.1993	0.79720 0.0019	1.00000 0.0	0.26244 0.4099	0.21836 0.4954	0.11559 0.7206	0.81818 0.0011	0.37063 0.2356	0.23077 0.4705	-0.34463 0.2726	-0.05801 0.8579	0.55245 0.0625	0.19298 0.5479	0.23776 0.4568	-0.06993 0.8290	0.25175 0.4299
FLOW	-0.31918 0.3119	-0.24825 0.4366	0.20569 0.5213	0.26953 0.3969	0.23407 0.4640	0.26953 0.3969	0.00709 0.9825	0.12767 0.6925	0.58949 0.0437	0.36174 0.2479	0.62418 0.0301	0.26244 0.4099	1.00000 0.0	0.48725 0.1081	0.12079 0.7084	0.06384 0.8438	-0.18442 0.5661	0.12058 0.7089	-0.40360 0.1932	-0.14709 0.6483	0.17732 0.5814	-0.11033 0.7329	0.22559 0.4813	-0.04255 0.8955	-0.67383 0.0163
REUSE	-0.21836 0.4954	-0.21836 0.4954	0.48038 0.1139	0.13101 0.6848	0.04367 0.8928	0.30570 0.3339	0.04367 0.8928	0.30570 0.3339	0.40832 0.1876	0.13101 0.6848	0.48038 0.1139	0.21836 0.4954	0.48725 0.1081	1.00000 0.0	-0.34998 0.2648	0.13101 0.6848	-0.21836 0.4954	0.21836 0.4954	-0.17750 0.5810	-0.22642 0.4792	0.30570 0.3339	0.17830 0.5858	0.04367 0.8928	-0.13101 0.6848	0.04367 0.8928
TEMP	-0.10158 0.7534	0.03503 0.9139	0.00000 1.0000	-0.05254 0.8712	-0.02452 0.9397	-0.62697 0.0291	0.21366 0.5049	-0.50788 0.0918	-0.24016 0.4521	0.22417 0.4837	0.04203 0.8968	0.11559 0.7206	0.12079 0.7084	-0.34998 0.2648	1.00000 0.0	0.15762 0.6247	0.22767 0.4767	0.15061 0.6403	-0.00890 0.9781	0.30871 0.3289	0.12609 0.6962	0.40949 0.1862	0.22767 0.4767	0.29422 0.3533	-0.26970 0.3966
FWI	-0.01399 0.9656	-0.17483 0.5868	0.04196 0.8970	-0.06294 0.8459	-0.30070 0.3423	-0.33566 0.2861	0.98601 0.0001	0.08392 0.7954	0.03632 0.9108	0.71329 0.0092	0.76923 0.0034	0.81818 0.0011	0.06384 0.8438	0.13101 0.6848	0.15762 0.6247	1.00000 0.0	0.73427 0.0065	0.67133 0.0168	0.18830 0.5578	-0.29005 0.3605	0.77622 0.0030	0.34035 0.2790	0.45154 0.1309	0.28671 0.3663	0.39860 0.1993
NH3	-0.01399 0.9656	-0.18182 0.5717	-0.12587 0.6967	-0.13986 0.6646	-0.27273 0.3911	-0.56643 0.0548	0.80420 0.0016	-0.23776 0.4568	0.02906 0.9286	0.49650 0.1006	0.40559 0.1908	0.37063 0.2356	-0.18442 0.5661	-0.21836 0.4954	0.22767 0.4767	0.73427 0.0065	1.00000 0.0	0.76224 0.0040	0.50806 0.0917	-0.37706 0.2270	0.77622 0.0030	0.38246 0.2198	0.47552 0.1182	0.69930 0.0114	0.34965 0.2652
TKN	-0.36364 0.2453	-0.48252 0.1121	-0.03497 0.9141	0.16084 0.6175	-0.17483 0.5868	-0.19580 0.5419	0.66434 0.0185	-0.00699 0.9828	0.33055 0.2940	0.79021 0.0022	0.54545 0.0666	0.23077 0.4705	0.12058 0.7089	0.21836 0.4954	0.15061 0.6403	0.67133 0.0168	0.76224 0.0040	1.00000 0.0	0.62885 0.0285	-0.42057 0.1734	0.78322 0.0026	0.57895 0.0486	0.58042 0.0479	0.51049 0.0899	0.24476 0.4433
NO2	-0.41568 0.1790	-0.50095 0.0971	-0.47964 0.1146	0.34818 0.2674	-0.16343 0.6118	-0.18475 0.5654	0.22738 0.4772	0.06395 0.8435	0.08858 0.7843	0.42634 0.1670	-0.11014 0.7333	-0.34463 0.2726	-0.40360 0.1932	-0.17750 0.5810	-0.00890 0.9781	0.18830 0.5578	0.50806 0.0917	0.62885 0.0285	1.00000 0.0	-0.30577 0.3338	0.21672 0.4987	0.36723 0.2403	0.04619 0.8867	0.49740 0.0999	0.38725 0.2136
NO3	-0.16678 0.6044	-0.05076 0.8755	-0.15227 0.6366	0.19578 0.5420	0.26104 0.4125	0.12327 0.7027	-0.31180 0.3238	0.15953 0.6204	-0.23352 0.4651	-0.33355 0.2894	-0.35531 0.2571	-0.05801 0.8579	-0.14709 0.6483	-0.22642 0.4792	0.30871 0.3289	-0.29005 0.3605	-0.37706 0.2270	-0.42057 0.1734	-0.30577 0.3338	1.00000 0.0	-0.50033 0.0976	0.17828 0.5793	-0.56559 0.0553	-0.50755 0.0921	-0.03626 0.9109
TP	0.08392 0.7954	-0.02797 0.9312	0.41259 0.1826	-0.31469 0.3191	-0.29371 0.3541	-0.39161 0.2081	0.77622 0.0030	-0.18182 0.5717	0.36687 0.2408	0.58042 0.0479	0.72727 0.0074	0.55245 0.0625	0.17732 0.5814	0.30570 0.3339	0.12609 0.6962	0.77622 0.0030	0.77622 0.0030	0.78322 0.0026	0.21672 0.4987	-0.50033 0.0976	1.00000 0.0	0.47369 0.1198	0.62937 0.0283	0.60140 0.0386	0.33566 0.2861
DP	-0.23860 0.4552	-0.17544 0.5855	0.15439 0.6319	0.02456 0.9396	-0.28421 0.3706	-0.16842 0.6008	0.32983 0.2951	0.12281 0.7038	0.20413 0.5245	0.31579 0.3173	0.23158 0.4689	0.19298 0.5479	-0.11033 0.7329	0.17530 0.5858	0.40949 0.1862	0.34035 0.2790	0.38246 0.2198	0.57895 0.0486	0.36723 0.2403	0.17828 0.5793	0.47369 0.1198	1.00000 0.0	0.13684 0.6715	0.15790 0.6241	0.47369 0.1198
TSS	0.25874 0.4168	0.18881 0.5557	0.37762 0.2262	-0.41259 0.1826	-0.16783 0.6021	-0.22378 0.4845	0.48455 0.1377	-0.47552 0.1182	0.02543 0.9375	0.52448 0.0800	0.39860 0.1993	0.23776 0.4568	0.20569 0.5213	0.04367 0.8928	0.22767 0.4767	0.46154 0.1309	0.47552 0.1182	0.58042 0.0479	0.04619 0.8867	-0.56559 0.0553	0.62937 0.0283	0.13684 0.6715	1.00000 0.0	0.32168 0.3079	-0.10490 0.7456
SIZE	0.04895 0.8799	-0.02098 0.9484	0.08392 0.7954	-0.23776 0.4568	-0.02098 0.9484	-0.72727 0.0074	0.39161 0.2081	-0.57343 0.0513	0.15619 0.6278	0.26573 0.4038	0.18182 0.5717	-0.06993 0.8290	-0.04256 0.8955	-0.13101 0.6848	0.29422 0.3533	0.28671 0.3663	0.69930 0.0114	0.51049 0.0899	0.49740 0.0999	-0.50758 0.0921	0.60140 0.0386	0.15790 0.6241	0.32168 0.3079	1.00000 0.0	0.02797 0.9312
HRT	0.13986 0.6646	0.05594 0.8629	0.04895 0.8799	-0.18182 0.5717	-0.56643 0.0548	-0.11189 0.7292	0.37762 0.2262	0.28671 0.3663	-0.07991 0.8050	0.02098 0.9484	0.00699 0.9828	0.25175 0.4299	-0.67383 0.0163	0.04367 0.8928	-0.26970 0.3966	0.39860 0.1993	0.34965 0.2652	0.24476 0.4433	0.38725 0.2136	-0.03626 0.9109	0.33566 0.2861	0.47369 0.1198	-0.10490 0.7456	0.02797 0.9312	1.00000 0.0

SPEARMAN CORRELATION ANALYSIS - GROUP D (NEW BRUNSWICK TANKS)

Spearman Correlation Coefficients / Prob > |R| under Ho: Rho=0 / N = 9

	m1	m2	m3	mCDC	INTPT	r^2	INTEN	PROD	AREA	DEPTH	CROP	DENS	FLOW	TEMP	NH3	TKN	TP	DP	TSS	SIZE	HRT
m1	1.00000 0.0	0.76667 0.0159	0.56667 0.1116	-0.73333 0.0246	-0.23333 0.5457	-0.88333 0.0016	-0.08333 0.8312	-0.38333 0.3085	-0.05000 0.8984	0.07833 0.8412	-0.13333 0.7324	0.11667 0.7650	-0.11667 0.7650	-0.48333 0.1875	-0.01667 0.9661	0.08333 0.8312	0.30126 0.4308	0.02554 0.9480	0.66667 0.0499	-0.13333 0.7324	-0.16667 0.6682
m2	0.76667 0.0159	1.00000 0.0	0.65000 0.0581	-0.43333 0.2440	0.08333 0.8312	-0.68333 0.0424	-0.38333 0.3085	-0.10000 0.7980	0.33333 0.3807	0.01741 0.9645	0.15000 0.7001	0.03333 0.9322	0.30000 0.4328	0.06667 0.8647	-0.08333 0.8312	-0.16667 0.6682	-0.20084 0.6044	-0.43414 0.2430	0.18333 0.6368	0.10000 0.7980	-0.36667 0.3317
m3	0.56667 0.1116	0.65000 0.0581	1.00000 0.0	-0.48333 0.1875	0.00000 1.0000	-0.66667 0.0499	-0.08333 0.8312	0.13333 0.7324	0.20000 0.6059	-0.23500 0.5427	0.06667 0.8647	0.16667 0.6682	0.06667 0.8647	-0.05000 0.8984	0.15000 0.7001	0.45000 0.2242	-0.09205 0.8138	-0.41712 0.2640	0.45000 0.2242	0.01667 0.9661	0.10000 0.7980
mCDC	-0.73333 0.0246	-0.43333 0.2440	-0.48333 0.1875	1.00000 0.0	0.73333 0.0246	0.68333 0.0424	-0.41667 0.2646	0.31667 0.4064	0.28333 0.4600	0.07833 0.8412	0.13333 0.7324	-0.56667 0.1116	0.25000 0.5165	0.60000 0.0876	-0.46667 0.2054	-0.56667 0.1116	-0.49373 0.1768	-0.16174 0.6776	-0.83333 0.0053	-0.16667 0.6682	0.05000 0.8984
INTPT	-0.23333 0.5457	0.08333 0.8312	0.00000 1.0000	0.73333 0.0246	1.00000 0.0	0.15000 0.7001	-0.81667 0.0072	0.36667 0.3317	0.56667 0.1116	-0.13056 0.7378	0.26667 0.4879	-0.68333 0.0424	0.46667 0.2054	0.60000 0.0876	-0.61667 0.0769	-0.50000 0.1705	-0.53557 0.1373	-0.22984 0.5519	-0.60000 0.0876	-0.45000 0.2242	-0.25000 0.5165
r^2	-0.88333 0.0016	-0.68333 0.0424	-0.66667 0.0499	0.68333 0.0424	0.15000 0.7001	1.00000 0.0	0.16667 0.6682	0.35000 0.3558	-0.13333 0.7324	0.13926 0.7208	0.06667 0.8647	0.00000 1.0000	-0.01667 0.9661	0.48333 0.1875	0.10000 0.7980	-0.21667 0.5755	-0.15900 0.6828	0.09364 0.8106	-0.58333 0.0992	0.15000 0.7001	-0.08333 0.8312
INTEN	-0.08333 0.8312	-0.38333 0.3085	-0.08333 0.8312	-0.41667 0.2646	-0.81667 0.0072	0.16667 0.6682	1.00000 0.0	-0.11667 0.7650	-0.56667 0.1116	0.41779 0.2632	-0.13333 0.7324	0.81667 0.0072	-0.51667 0.1544	-0.43333 0.2440	0.81667 0.0072	0.60000 0.0876	0.60252 0.0860	0.22984 0.5519	0.38333 0.3085	0.55000 0.1250	0.46667 0.2054
PROD	-0.38333 0.3085	-0.10000 0.7980	0.13333 0.7324	0.31667 0.4064	0.36667 0.3317	0.35000 0.3558	-0.11667 0.7650	1.00000 0.0	0.66667 0.0499	0.08704 0.8238	0.81667 0.0072	0.15000 0.7001	0.68333 0.0424	0.81667 0.0072	-0.01667 0.9661	-0.06667 0.8647	-0.60252 0.0860	-0.56183 0.1154	-0.43333 0.2440	0.28333 0.4600	-0.26667 0.4879
AREA	-0.05000 0.8984	0.33333 0.3807	0.20000 0.6059	0.28333 0.4600	0.56667 0.1116	-0.13333 0.7324	-0.56667 0.1116	0.66667 0.0499	1.00000 0.0	0.03482 0.9291	0.85000 0.0037	-0.20000 0.6059	0.96667 0.0001	0.73333 0.0246	-0.41667 0.2646	-0.41667 0.2646	-0.81172 0.0079	-0.75762 0.0180	-0.58333 0.0992	0.21667 0.5755	-0.25000 0.5165
DEPTH	0.07833 0.8412	0.01741 0.9645	-0.23500 0.5427	0.07833 0.8412	-0.13056 0.7378	0.13926 0.7208	0.41779 0.2632	0.08704 0.8238	0.03482 0.9291	1.00000 0.0	0.33075 0.3846	0.46131 0.2113	0.03611 0.9468	0.06093 0.8763	0.29593 0.4394	-0.26112 0.4974	0.17481 0.6528	-0.16449 0.6724	-0.21760 0.5738	0.56575 0.1123	0.15667 0.6873
CROP	-0.13333 0.7324	0.15000 0.7001	0.06667 0.8647	0.13333 0.7324	0.26667 0.4879	0.06667 0.8647	-0.13333 0.7324	0.81667 0.0072	0.85000 0.0037	0.33075 0.3846	1.00000 0.0	0.26667 0.4879	0.88333 0.0016	0.71667 0.0298	0.00000 1.0000	-0.21667 0.5755	-0.55904 0.1098	-0.64695 0.0597	-0.50000 0.1705	0.51667 0.1544	-0.28333 0.4600
DENS	0.11667 0.7650	0.03333 0.9322	0.16667 0.6682	-0.56667 0.1116	-0.68333 0.0424	0.00000 1.0000	0.81667 0.0072	0.15000 0.7001	-0.20000 0.6059	0.46131 0.2113	0.26667 0.4879	1.00000 0.0	-0.11667 0.7650	-0.13333 0.7324	0.91667 0.0005	0.56667 0.1116	0.41841 0.2624	-0.03405 0.9307	0.30000 0.4328	0.73333 0.0246	0.08333 0.8312
FLOW	-0.11667 0.7650	0.30000 0.4328	0.06667 0.8647	0.25000 0.5165	0.46667 0.2054	-0.01667 0.9661	-0.51667 0.1544	0.68333 0.0424	0.96667 0.0001	0.03611 0.9468	0.88333 0.0016	-0.11667 0.7650	1.00000 0.0	0.78333 0.0125	-0.35000 0.3558	-0.45000 0.2242	-0.81172 0.0079	-0.71506 0.0304	-0.61667 0.0769	0.30000 0.4328	-0.40000 0.2861
TEMP	-0.48333 0.1875	0.06667 0.8647	-0.05000 0.8984	0.60000 0.0876	0.60000 0.0876	0.48333 0.1875	-0.43333 0.2440	0.81667 0.0072	0.73333 0.0246	0.06093 0.8763	0.71667 0.0298	-0.13333 0.7324	0.78333 0.0125	1.00000 0.0	-0.23333 0.5457	-0.46667 0.2054	-0.82009 0.0068	-0.65547 0.0553	-0.78333 0.0125	0.25667 0.4879	-0.41667 0.2646
NH3	-0.01667 0.9661	-0.08333 0.8312	0.15000 0.7001	-0.46667 0.2054	-0.61667 0.0769	0.10000 0.7980	0.81667 0.0072	-0.01667 0.9661	-0.41667 0.2646	0.29593 0.4394	0.00000 1.0000	0.91667 0.0005	-0.35000 0.3558	-0.23333 0.5457	1.00000 0.0	0.71667 0.0298	0.56904 0.1098	0.17025 0.6614	0.31667 0.4064	0.55667 0.1116	0.18333 0.6368
TKN	0.08333 0.8312	-0.16667 0.6682	0.45000 0.2242	-0.56667 0.1116	-0.50000 0.1705	-0.21667 0.5755	0.60000 0.0876	-0.06667 0.8647	-0.41667 0.2646	-0.25112 0.4974	-0.21667 0.5755	0.56667 0.1116	-0.45000 0.2242	-0.46667 0.2054	0.71667 0.0298	1.00000 0.0	0.56067 0.1163	0.29794 0.4362	0.63333 0.0671	0.06667 0.8647	0.36667 0.3317
TP	0.30126 0.4308	-0.20084 0.6044	-0.09205 0.8138	-0.49373 0.1768	-0.53557 0.1373	-0.15900 0.6828	0.60252 0.0860	-0.60252 0.0860	-0.81172 0.0079	0.17481 0.6528	-0.55904 0.1098	0.41841 0.2624	-0.81172 0.0079	-0.82009 0.0068	0.56904 0.1098	0.56067 0.1163	1.00000 0.0	0.81208 0.0078	0.67783 0.0448	-0.15900 0.6828	0.20921 0.5890
DP	0.02554 0.9480	-0.43414 0.2430	-0.41712 0.2640	-0.16174 0.6776	-0.22984 0.5519	0.09364 0.8106	0.22984 0.5519	-0.56183 0.1154	-0.75762 0.0180	-0.16449 0.6724	-0.64695 0.0597	-0.03405 0.9307	-0.71506 0.0304	-0.65547 0.0553	0.17025 0.6614	0.29794 0.4362	0.81208 0.0078	1.00000 0.0	0.46819 0.2037	-0.55332 0.1222	-0.05108 0.8962
TSS	0.66667 0.0499	0.18333 0.6368	0.45000 0.2242	-0.83333 0.0053	-0.60000 0.0876	-0.58333 0.0992	0.38333 0.3085	-0.43333 0.2440	-0.58333 0.0992	-0.21760 0.5738	-0.50000 0.1705	0.30000 0.4328	-0.61667 0.0769	-0.78333 0.0125	0.31667 0.4064	0.63333 0.0671	0.67783 0.0448	0.46819 0.2037	1.00000 0.0	-0.26667 0.4879	0.08333 0.8312
SIZE	-0.13333 0.7324	0.10000 0.7980	0.01667 0.9661	-0.16667 0.6682	-0.45000 0.2242	0.15000 0.7001	0.55000 0.1250	0.28333 0.4600	0.21667 0.5755	0.56575 0.1123	0.51667 0.1544	0.73333 0.0246	0.30000 0.4328	0.26667 0.4879	0.56667 0.1116	0.06667 0.8647	-0.15900 0.6828	-0.55332 0.1222	-0.26667 0.4879	1.00000 0.0	0.18333 0.6368
HRT	-0.16667 0.6682	-0.36667 0.3317	0.10000 0.7980	0.05000 0.8984	-0.25000 0.5165	-0.08333 0.8312	0.46667 0.2054	-0.26667 0.4879	-0.25000 0.5165	0.15667 0.6873	-0.28333 0.4600	0.08333 0.8312	-0.40000 0.2861	-0.41667 0.2646	0.18333 0.6368	0.36667 0.3317	0.20921 0.5890	-0.05108 0.8962	0.08333 0.8312	0.18333 0.6368	1.00000 0.0

APPENDIX IV
Effluent Treatment Facilities Data

FARM #	GROUP	TYPE	AREA	FLOW	Vo	INLET	OUTLET	HRT	DEPTH	SLOPE	INTERC	SIZE	TSS	TKN	TP	DP
19	2	1	22.4	5237	233.8	3.74	1494.1	8.00	1.30	0.7067	0.0269	93	0.338	0.761	0.310	0.979
24	2	1	58.0	17020	293.4	1.86	2326.7	4.50	0.91	0.4641	0.1760	52	1.685	0.959	2.190	3.000
55	1	1	26.0	982	37.8	4.94	1025.5	30.90	0.81	0.7771	-0.5019	510	0.352	0.897	0.529	1.359
6	2	1	47.6	11259	236.5	5.22	2308.7	6.51	1.07	0.8304	0.6301	450	0.000	0.707	0.309	1.229
47	2	1	5.4	6186	1145.6	4.12	3691.5	1.00	0.81	0.3270	0.2774	113	0.548	0.735	0.833	0.984
8	1	1	3.0	393	131.0	1.30	820.8	5.81	0.53	0.6152	-0.4816	133	1.102	1.106	1.000	1.600
3	1	1	18329	246.7	2.23	7516.8	5.34	0.91	0.4994	-0.2431	250	1.225	0.853	0.871	1.007	
5	2	1	23.8	2749	115.5	5.07	563.7	12.97	1.04	0.6121	0.4028	341	0.000	1.114	2.200	2.833
70	1	1	16.7	1375	82.3	2.23	751.9	21.30	1.22	0.3522	-0.2688	135	0.651	0.807	0.658	1.060
82	1	1	13.0	2618	201.4	1.63	1227.0	5.45	0.76	0.7607	0.6077	170	0.948	0.990	0.964	1.012
23	1	1	10.9	2618	240.2	2.51	954.4	5.47	0.91	0.8865	-0.5626	133	0.905	0.909	1.045	1.250
35	1	2	12.3	1571	127.7	0.04	1230.5	9.74	0.86	1.0696	0.2626	360	1.138	1.036	1.259	0.842
62	1	2	31.2	393	12.6	0.01	1289.4	57.90	0.76	0.8308	-0.0337	242	0.483	0.724	0.384	0.696
66	1	2	69.1	1212	17.5	0.60	1325.5	56.70	0.69	0.5417	0.3136	90	0.275	0.825	0.393	1.000
21	1	2	11.1	2095	188.7	3.40	547.0	6.88	0.90	0.8769	0.1208	426	0.742	0.517	0.487	4.167
7	1	2	26.0	2160	83.1	0.74	1012.4	7.03	0.41	0.6063	-0.2277	93	0.779	1.895	0.562	2.333
86	4	3	445.9	17478	39.2	0.20	25966.4	33.60	0.91	0.4108	0.3821	13	0.978	1.074	0.681	1.048
84	4	3	278.7	2291	8.2	0.08	1595.0	160.20	0.91	0.1641	0.1082	35	0.226	0.713	0.715	1.000
90	4	3	1800.0	74304	41.3	0.45	4157.0	34.90	1.00	0.5593	0.7640	14	2.136	0.918	0.831	1.200
83	4	3	2000.0	10224	5.1	0.29	889.8	422.50	1.50	0.3824	0.4420	12	0.075	0.894	0.622	1.000
93	4	3	144.0	1702	11.8	0.16	1861.3	222.90	1.83	0.3212	-0.3128	29	0.450	0.958	0.901	0.870
88	4	3	8640.0	48567	5.6	1.04	2377.5	384.30	1.50	0.3191	0.3335	61	NA	0.996	1.531	1.125
91	4	3	860.4	10768	12.5	5.85	560.8	140.30	1.22	0.8801	0.4122	56	0.800	0.980	1.196	1.143
18	3	3	65.7	1636	24.9	0.07	1708.5	35.24	3.66	1.2342	-0.3970	114	0.898	1.026	1.104	1.300
23	1	3	672.5	13092	19.5	0.38	5859.6	906.20	3.06	0.8865	-0.5626	133	0.681	0.610	0.368	0.320
28	3	4	0.7	1309	1870.0	0.02	2734.0	0.40	0.48	1.1291	0.7530	5	1.300	1.000	1.300	0.500
50	1	4	1.2	524	436.7	0.02	820.8	4.50	1.37	0.4826	0.5803	242	0.904	0.938	0.994	1.047
20	3	4	1.2	196	167.5	0.02	409.4	6.55	0.76	0.7809	-0.2835	3	1.565	1.018	1.414	1.625
56	2	4	5.9	982	166.4	0.02	2051.1	7.00	0.81	0.9455	0.5147	182	0.000	1.029	1.081	1.370
29	3	4	65.7	884	13.5	1.75	30.8	130.50	1.22	0.7393	-0.2779	370	0.705	0.901	1.444	1.520
19	2	4	26.3	1309	49.8	0.52	72.0	44.09	1.52	0.7067	0.0269	93	1.320	0.863	0.363	0.289
45	3	4	64.4	1309	20.3	0.04	1367.0	70.20	0.99	1.2140	0.2605	182	0.693	0.435	1.287	1.707
34	3	4	65.7	1964	29.9	0.03	73.3	73.40	1.52	0.6039	-0.2629	193	0.272	0.341	0.246	0.480

CANADIAN AQUACULTURE SYSTEMS

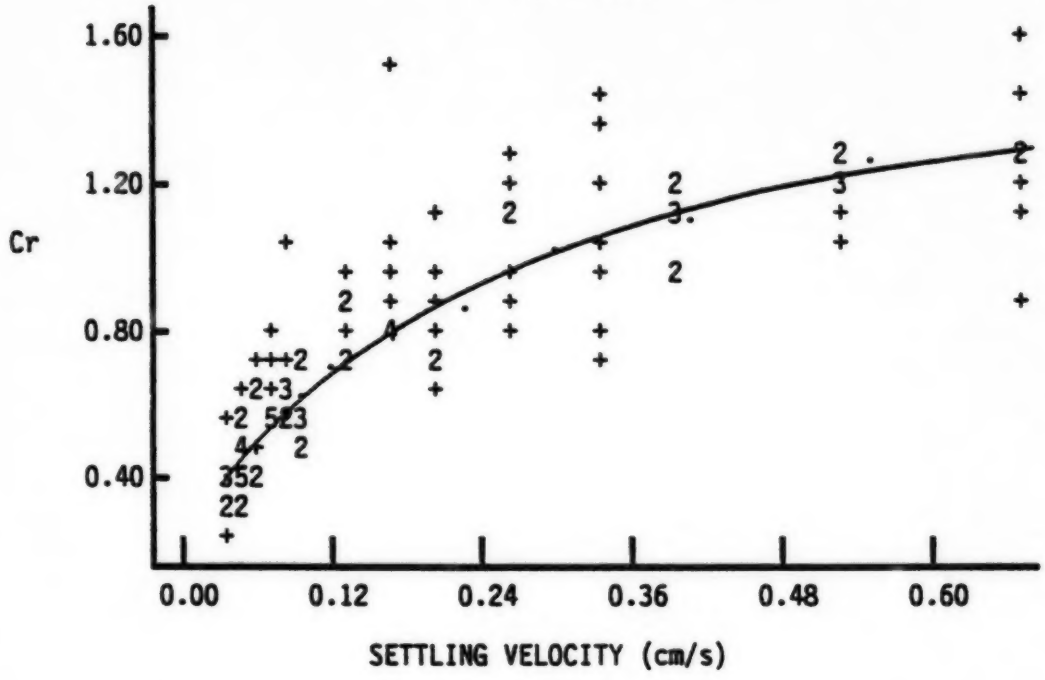
APPENDIX IV (cont'd)
Effluent Treatment Facilities Data

	AREA	FLOW	Vo	INLET	OUTLET	HRT	DEPTH	SLOPE	INTERC	SIZE	TSS	TKN	TP	OP
TYPE 1 - In-Raceway (n=11)														
MEAN	27.4	6251.5	269.5	3.17	2061.9	9.75	0.93	0.6210	0.0057	216	0.705	0.894	0.992	1.483
MIN	3.0	393.0	37.8	1.30	563.7	1.00	0.53	0.3270	-0.5626	52	0.000	0.707	0.309	0.979
MAX	74.3	18329.0	1145.6	5.22	7516.8	30.90	1.30	0.8865	0.6301	510	1.685	1.114	2.200	3.000
S.D.	21.9	6123.6	287.3	1.41	1939.2	8.42	0.21	0.1819	0.4230	146	0.502	0.133	0.618	0.701
TYPE 2 - External Rectangular (n=5)														
MEAN	29.9	1486.2	85.9	0.96	1081.0	27.65	0.72	0.7851	0.0871	242	0.683	0.999	0.617	1.808
MIN	11.1	393.0	12.6	0.01	547.0	6.88	0.41	0.5417	-0.2277	90	0.275	0.517	0.384	0.696
MAX	69.1	2160.0	188.7	3.40	1325.5	57.90	0.90	1.0696	0.3136	426	1.138	1.895	1.259	4.167
S.D.	21.1	648.4	66.9	1.26	288.2	24.23	0.17	0.1911	0.1985	136	0.292	0.478	0.328	1.316
TYPE 3 - External Pond (n=9)														
MEAN	1656.4	20006.9	18.7	0.95	4997.3	260.02	1.73	0.5731	0.1300	52	0.781	0.908	0.883	1.001
MIN	65.7	1636.0	5.1	0.07	560.8	33.60	0.91	0.1641	-0.5626	12	0.075	0.610	0.368	0.320
MAX	8640.0	74304.0	41.3	5.85	25966.4	906.20	3.66	1.2342	0.7640	133	2.136	1.074	1.531	1.300
S.D.	2553.7	23536.1	13.0	1.76	7577.7	266.15	0.93	0.3313	0.4266	42	0.593	0.143	0.329	0.268
TYPE 4 - External Circular (n=8)														
MEAN	28.9	1059.6	344.3	0.30	944.8	42.08	1.08	0.8253	0.1639	159	0.845	0.816	1.016	1.067
MIN	0.7	196.0	13.5	0.02	30.8	0.40	0.48	0.4826	-0.2835	3	0.000	0.341	0.246	0.289
MAX	65.7	1964.0	1870.0	1.75	2734.0	130.50	1.52	1.2140	0.7530	370	1.565	1.029	1.444	1.707
S.D.	29.2	509.2	591.5	0.57	952.8	43.64	0.36	0.2366	0.3951	115	0.505	0.254	0.436	0.535
N.B. Ponds Only (n=7)														
MEAN	2024.1	23619.1	17.7	1.15	5344.0	199.81	1.27	0.4339	0.3042	31	0.778	0.933	0.925	1.055
MIN	144.0	1702.0	5.1	0.08	560.8	33.60	0.91	0.1641	-0.3128	12	0.075	0.713	0.622	0.870
MAX	8640.0	74304.0	41.3	5.85	25966.4	422.50	1.83	0.8801	0.7640	61	2.136	1.074	1.531	1.200
S.D.	2783.8	25379.7	14.5	1.94	8488.6	143.47	0.33	0.2127	0.3089	19	0.682	0.105	0.304	0.103

APPENDIX V
Regression Analysis
New Brunswick Smolt Production Facility Settling Data

CUMULATIVE DISTRIBUTION EFFLUENT SOLIDS SETTLING CURVE
FOR NEW BRUNSWICK SMOLT PRODUCTION OPERATIONS

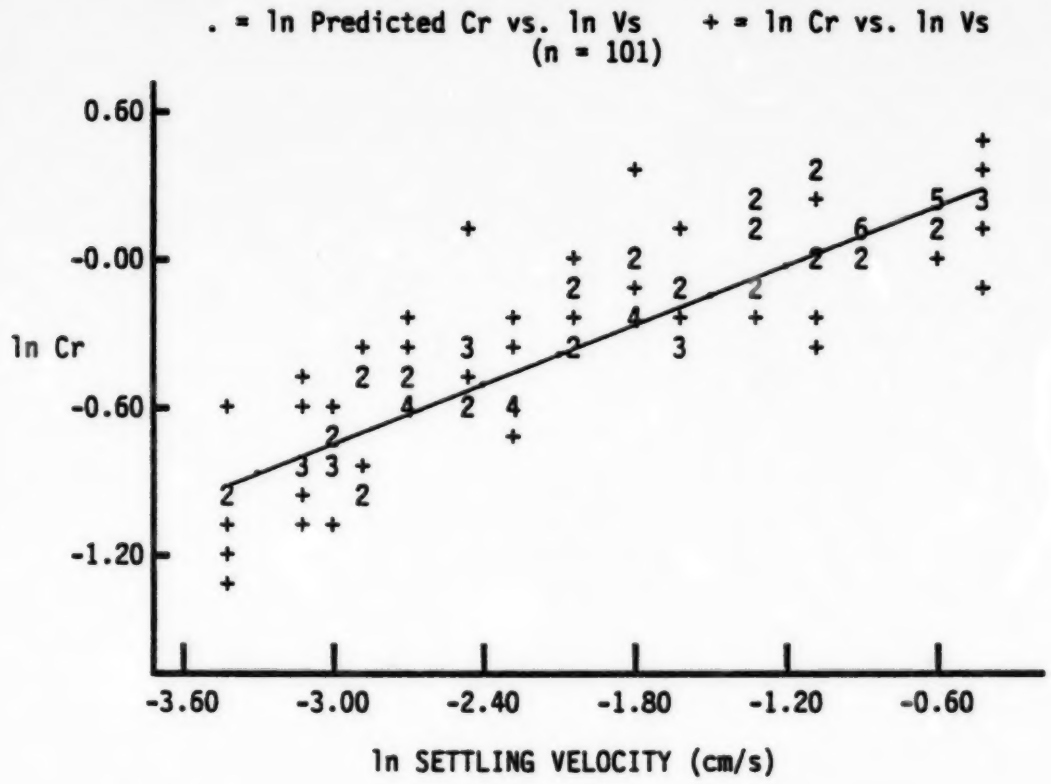
. = Predicted Cr vs. Vs + = Cr vs. Vs
(n = 101)



The raw data, plotted here, illustrate a strong curvilinear relationship between the settling velocity of effluent suspended solids and the fraction of solids (Cr) having a settling velocity less than that value on the abscissa. Numerals on the graph indicate co-ordinates where multiple data points fall; the value represents the number of data at that co-ordinate.

CANADIAN AQUACULTURE SYSTEMS

CUMULATIVE DISTRIBUTION EFFLUENT SOLIDS SETTLING CURVE
FOR NEW BRUNSWICK SMOLT PRODUCTION OPERATIONS



The ln transformed data, plotted here, illustrate a significant linear relationship (regression statistics are presented below) between the ln settling velocity of effluent suspended solids and the ln fraction of solids (Cr) having a settling velocity less than that value on the abscissa. Numerals on the graph indicate co-ordinates where multiple data points fall; the value represents the number of data at that co-ordinate.

The use of ln transformed data may, to some readers, appear to manipulate data to present significant results. In actuality, data transformations do not adjust data to present something that was not already present in the findings. Rather, transformations simply alter the scale of the observed variables into a format which is more manageable, and more meaningful in the interpretation and implementation of research results. In this case, ln transformation has taken data which are multiplicative on a linear scale and presented it as an additive system on a logarithmic scale. The data have not been manipulated in any manner to present information which is not inherent in the numbers.

Confidence limits are routinely used to assess the accuracy of observations. Caution must be used in interpreting confidence limits, however. When evaluating data on a transformed scale, back-transformation of mean results are reliable and meaningful. Back-transformation of confidence limits, however, can be misleading. Frequently, depending on the transformation, the back-transformed

confidence limits are asymmetrical, and this must be accounted for in data interpretation. Confidence limits for the regression equation are presented at the end of the regression statistics which follow.

REGRESSION ANALYSIS (ln Transformed Data)

THE APPROXIMATED T VALUE WITH
99 DEGREES OF FREEDOM IS: 1.984662

THE REGRESSION STATISTICS ARE AS FOLLOWS:

THE EQUATION OF THE LINE IS: Y= .4777041 + .3980361 X

WHERE THE SLOPE IS: .3980361
AND THE Y-INTERCEPT IS: .4777041
THE STANDARD ERROR OF THE REGRESSION IS: (+ OR -) .206535
THE STANDARD ERROR OF THE SLOPE IS: (+ OR -) 2.222518E-02
THE 95% C.L. FOR THE SLOPE ARE: .3539267 .4421456
THE STANDARD ERROR OF THE INTERCEPT IS: (+ OR -) 4.788652E-02
THE 95% C.L. FOR THE INTERCEPT ARE: .3826656 .5727426
THE CORRELATION COEFFICIENT (R) IS: .8741512
THE COEFFICIENT OF DETERMINATION (R**2) IS: .7641403

THE REGRESSION COMPUTATIONS HAVE PRODUCED THE FOLLOWING:

THE MEANS OF X AND Y ARE: -1.946102 -.2969148
THE SUM OF X IS: -196.5563
THE SUM OF Y IS: -29.98839
THE SUM OF X-SQUARED IS: 468.8755
THE SUM OF Y-SQUARED IS: 26.80877
THE SUM OF X*Y IS: 92.73362
THE SUM OF SQUARES OF X IS: 86.35688
THE SUM OF CROSS-PRODUCTS IS: 34.37315
THE REGRESSION SUM OF SQUARES IS: 13.68176
THE RESIDUAL SUM OF SQUARES IS: 4.223014
THE TOTAL SUM OF SQUARES IS: 17.90477
THE REGRESSION MEAN SQUARE IS: 13.68176
THE RESIDUAL MEAN SQUARE IS: 4.265671E-02

THE F-VALUE IS: 320.7411
WITH 1 REGRESSION D OF F, AND
A RESIDUAL D OF F OF: 99

CANADIAN AQUACULTURE SYSTEMS

FOR THE RECIPROCAL REGRESSION OF X ON Y:

THE EQUATION OF THE LINE IS: X=-1.376092 + 1.919776 Y
OR
THE EQUATION OF THE LINE IS: Y= .7167981 + .520894 X

THE GEOMETRIC MEAN REGRESSION RESULTS ARE:

(I.E. A MODEL II REGRESSION
ALSO CALLED THE REDUCED MAJOR AXIS OR THE G.M.R.).

THE EQUATION OF THE LINE IS: Y= .5892235 + .4553401 X

WHERE THE SLOPE IS: .4553401
AND THE INTERCEPT IS: .5892235
THE STANDARD ERROR OF THE SLOPE IS: 2.222518E-02
THE 95% C.L. OF THE SLOPE ARE: .4112306 .4994496
THE STANDARD ERROR OF THE INTERCEPT IS: 4.788652E-02
THE 95% C.L. OF THE INTERCEPT ARE: .4941849 .684262

ADDITIONAL STATISTICS FOR THE REGRESSION FOLLOW:

USING THE LS REGRESSION RESULTS...
THE PREDICTED VALUES AND 95% C.L. FOR Y ARE:

GIVEN X VALUE	PREDICTED Y	LOWER Y	UPPER Y	ERROR
ln Vs	Pred ln Cr			
-3.3	-0.83582	-0.90813	-0.76350	0.03644
-3.0	-0.71640	-0.77825	-0.65456	0.03116
-2.7	-0.59699	-0.64962	-0.54439	0.02652
-2.4	-0.47758	-0.52302	-0.43214	0.02289
-2.1	-0.35817	-0.39952	-0.31682	0.02083
-1.8	-0.23876	-0.28805	-0.19749	0.02021
-1.5	-0.11935	-0.16464	-0.07406	0.02282
-1.2	0.00006	-0.05235	-0.05247	0.02641
-0.9	0.11947	0.05789	0.18106	0.03103
-0.6	0.23888	0.16685	0.31092	0.03630